EFFECT OF CURING TEMPERATURE ON THE STRENGTH OF LIME STABILIZED FLY ASH

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of

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In
Civil Engineering

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This is to certify that the thesis entitled, "**Effect of Curing Temperature on the Strength of Lime Stabilized Fly Ash**" submitted by **Aparupa Pani** in partial fulfillment of the requirement for the award of **Master of Technology** degree in **Civil Engineering** with specialization in **Geotechnical Engineering** at the National Institute of Technology Rourkela is an authentic work carried out by her under our supervision and guidance. To the best of our knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any degree or diploma.

Place: Rourkela

Date:

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Aparupa Pani

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LIST OF SYMBOLS

Notation	**Description**
E	Compaction Energy, kJ/m3
OMC	Optimum Moisture Content, %
MDD	Maximum Dry Density, kN/m3;
UCS	Unconfined Compressive Strength, kN/m3
FS	Failure Strain, %
MC	Moisture Content, %
CBR	California Bearing Ratio, %
C_u	Coefficient of uniformity
C_c	Coefficient of uniformity
G	Specific Gravity
k	coefficient of permeability, cm/sec

ABSTRACT

In India major source of power generation is coal based thermal power plants .where 57% of the total power generated is from coal-based thermal power plant. High ash content is found to be in range of 30% to 50% in Indian coal. The quantum of Fly Ash produced depends on the quality of coal used and the operating conditions of thermal power plants. Presently the annual production of Fly Ash in India is about 112 million tonnes with 65000 acre of land being occupied by ash ponds and is expected to cross 225 million tonnes by the year 2017. Such a huge quantity does cause challenging problems, in the form of land usage, health hazards and environmental dangers. Both in disposal as well as in utilization, utmost care has to be taken to safeguard the interest of human life, wild life and environment.

Fly ash is generally classified into two types; Class C and Class F. Class C fly ash contains high calcium content which is highly reactive with water even in absence of lime. Class F ash contains lower percentage of lime. The main work carried out is to investigate the suitability of class F fly ash, containing CaO as low as 1.4%, modified with added lime as a construction material in different civil engineering fields.

These waste products are generally toxic in nature, easily ignitable, corrosive and reactive easily and therefore cause detrimental effects on the environment. Fly Ash particles ranging in size from 0.5 to 300 micron in equivalent diameter, being light weight, have potential to get airborne easily and pollute the environment. If not managed properly Fly Ash disposal in sea/rivers/ponds can cause damage to aquatic life also. Slurry disposal lagoons/ settling tanks can become breeding grounds for mosquitoes and bacteria. It can also contaminate the under-ground water resources with traces of toxic metals present in it.

Thus disposal of these wastes properly is one of the major concerns to be dealt with in the present generation. An innovative solution which would be effective, efficient and environmentally approved is required to overcome this problem of disposal. So with proper treatment the wastes can be used in many construction aspect like construction of highways, embankments etc.

For popularizing the usage of fly ash as one of the dominant construction material, it is advisable to enhance and improve some properties of it by stabilizing it by addition of some

suitable stabilizer like lime. This project work aims at evaluation of the effectiveness of addition of lime as an agent in stabilizing the waste product like fly ash and its suitability to be used as a construction material for structural fills and embankment materials. Fly ash used for experimentation in this project was collected from the thermal power plant of CPP- NSPCL, Rourkela Steel Plant .For evaluating the suitability of any construction material for various geotechnical engineering works its consistency properties, compaction properties, strength parameters and settlement properties are the most important properties to be tested.

In this project, an attempt was made to evaluate the above stated geo-engineering properties of fly ash along with the treated fly ash with different proportion of lime. The overall testing program was conducted in two phases. In the first phase, the physical, chemical and engineering properties of the fly ash samples were studied by conducting Hydrometer analysis, light and heavy compaction test, UCS test, Permeability test and CBR test. In the second phase of the test program, fly ash was mixed with 2%, 4%, 8% and 12% of lime as a percentage of dry weight of Fly ash. The particular UCS (sealed and unsealed)samples were cured for 7, 15, 30, and 60 days with varying temperature of 10°C, 25°C, 45°C and 90°C respectively with compactive energy 595 kJ/m3 to 2483 kJ/m3 to evaluate the effect of curing temperature on strength of lime stabilized flyash. Sealed samples were coated with wax for 10°C, 25°C, 45°C temperature and for higher temperature the sealed samples were coated with heat resistant polythene cover for preventing the UCS samples from outer moisture. Then comparison study has been done between sealed and unsealed samples. Then to study the effect of curing period on CBR value stabilized Fly ash samples were made with different percentage of lime (0%, 2%, 4%, 8%, and 12%) at a MDD and OMC corresponding to the compaction energy of 593 and 2483 kJ/m^3 and these samples were cured for 7 days and 30 days with soaking period of 4 days for soaked samples. Comparison study has been done between soaked and unsoaked CBR with varying compactive energy and curing period simultaneously.

CHAPTER 1

1.1 Introduction

Fly Ash is a by-product material generated by thermal power plants from combustion of Pulverized coal. This is a fine residue produced from the burnt coal is carried in the flue gas, separated by electrostatic precipitators, and collected in a field of hoppers. This residue which is collected is called as fly ash and is considered to be an industrial waste which can be used in the construction industry. Fly ash is one of the major industrial wastes used as a construction material. The fly ash can either be disposed of in the dry form or the wet method in which it can also be mixed with water and discharged as slurry into locations called ash ponds. Disposal of residual waste is one of the greatest challenges faced by the manufacturing industries in India.

In many countries, including India, coal is used as a primary fuel in thermal power stations and in other industries. Four countries, namely, China, India, Poland, and the United States, together produce more than 270 million tonnes of fly ash every year and less than half of it is used. The coal reserve of India is approximately 200 billion tonnes and its annual production reaches 250 million tones approximately. Unlike the developed countries, in India, the ash content present in the coal which is used for power generation is about 30-40%. The generation of ash has increased to about 131 million tonne during 2010-11 and is expected to grow further.

In India major source of power generation is coal based thermal power plants .where about 57% of the total power obtained is from coal-based thermal power plant. High ash content is found to be in range of 30% to 50% in Indian coal. The quantum of Fly Ash produced depends on the quality of coal used and the operating conditions of thermal power plants. Presently the annual production of Fly Ash in India is about 112 million tonnes with 65000 acre of land being occupied by ash ponds and is expected to cross 225 million tonnes by the year 2017. Such a huge quantity does cause challenging problems, in the form of land usage, health hazards and environmental dangers. Both in disposal as well as in utilization, utmost care has to be taken to safeguard the interest of human life, wild life and environment. When pulverized coal is burnt to generate heat, the residue contains 80% Fly Ash and 20% bottom ash.

Fig 1.1 Wet disposal of flyash

Fig 1.2 Dry disposal of flyash

1.2 Fly Ash: An Overview

Fly ash is a fine powdery material recovered from the gases while burning coal during the production of electricity in the thermal power stations. These micron-sized earth elements consist primarily of silica, alumina and iron. When fly-ash is mixed with lime and water, a cementitious compound is formed which possess the properties very similar to that of Portland cement. Because of this similarity in properties, fly ash can be used as a great replacement for a portion of cement in the concrete, which provides advantages in the quality. The concrete which is produced with the usage of flyash is denser in nature which results in a tighter, smoother surface with less bleeding. Fly ash concrete provides an impressive architectural benefit with expertise textural consistency and sharper detail. Fly Ash can also be called as Coal ash, Pulverized Flue ash, and Pozzolana. Fly ash is very similar to the volcanic ashes used in production of the earliest known hydraulic cements which were about 2,300 years ago. Those types of cements were produced near the small Italian town of Pozzuoli - which later inspired its name to be termed as "pozzolan".

1.3 Classification of Fly Ash

According to ASTM C618-03(2003a) there are two major classes of fly ash which are recognized. These two classes are dependent on the type of coal burned and are designated as:

a) Class C
b) Class F.

Class C fly ashes, containing usually more than 15% CaO are also called as high calcium ashes, became readily available for use in concrete industry .Class C fly ashes are not only pozzolanic in nature but are invariably self cementitious in property. Class C type of fly ash has a presence of high calcium content which is highly reactive with water even in the absence of lime.

Class F type of fly ash is generally produced by burning anthracite or bituminous coal contains lower percentage of lime. While Class C fly ash is generally obtained by burning sub-bituminous or lignite coal, at present, no appreciable amount of anthracite coal is used for generation of power. Essentially all Class F type of fly ashes presently available is derived basically from bituminous coal. Class F fly ashes which have calcium oxide (CaO) content less than 6%, are designated as low calcium ashes, and are not self-hardening in nature but generally exhibit pozzolanic properties. In these ashes unburned carbon content is more than 2% and is determined by loss on ignition (LOI) test. Quartz, mullite and hematite are the major types of crystalline phases identified fly ashes, which are derived from bituminous coal. Therefore, major research concerning the usage of fly ash in cement and concrete are dealt with Class F type. Previous research findings and majority of current industry practices have already proved that satisfactory and acceptable level of concrete mix can be produced with the Class F fly ash replacing cement weight by 15-30%. Use of Class F fly ash in general reduces quantity of water demand as well as the heat of hydration. The Concrete produced from Class F fly ash also exhibits the properties like improved resistance to sulphate attack and Chloride ion ingress.

The main objective is to investigate the suitability of class F type of fly ash which contains CaO as low as 1.4%, which is then modified by adding lime as a construction material. Utilization of Fly ash on a large scale in geotechnical constructions works would enable to reduce the disposal problems faced by the thermal power plants mostly due to its properties which are closely related to the natural earth material. So assessment of the nature of fly ash at different condition is required before using it in construction domain.

1.4 Impact of Fly Ash on Environment

A huge volume of Fly Ash produced from coal-based thermal power plants may bring several problems from environmental point of view. These waste products are generally toxic in nature, easily ignitable, corrosive and reactive easily and therefore cause detrimental effects on the environment. Fly Ash particles ranging in size from 0.5 to 300 micron in equivalent diameter, being light weight, have potential to get airborne easily and pollute the environment. If not managed properly Fly Ash disposal in sea/rivers/ponds can cause damage to aquatic life also. Slurry disposal lagoons/ settling tanks can become breeding grounds for mosquitoes and bacteria. It can also contaminate the under-ground water resources with traces of toxic metals present in Fly Ash. Huge investments/ expenditures are made just to get Fly Ash out from the thermal power plants and dump it in the ponds. If understood and managed properly, it can prove to be a valuable resource material.

Thus disposal of these wastes properly is one of the major concerns to be dealt with in the present generation. An innovative solution which would be effective, efficient and environmentally approved is required to overcome this problem of disposal. One of the solutions which are applicable is utilization of waste products from one industry as raw materials of some other industries, and hence reducing the burden on the environment. Many industrial wastes are utilized in construction industries. If this supply chain is maintained properly then it would enable the organizations to reduce the disposal problems to a great extent. The wastes can be used in construction of highways, embankments etc. Another problem that exists is that there no sufficient amount of soil of desired quality which is required for the construction purposes. The search for desired quality of soil again leads to deforestation and hence affecting soil erosion and agriculture productivity.

Cost of increase in good quality raw materials is also increasing to a high level. So efficient and effective utilization of the waste materials that is used as a substitute for the natural soil would not only help to reduce the disposal problem but also enable the organizations to preserve soil and reduce deforestation. This would be of huge benefit to the government and the country as a whole as it would help to conserve the natural resources, reduce the volume of waste to landfills, lower the cost of construction materials as well as the waste disposal cost.

1.5 Strength Characteristic of Flyash

For popularizing the usage of fly ash as one of the dominant construction material, it is advisable to enhance and improve some properties of it by stabilizing it by addition of some suitable stabilizer like lime. This project work aims at evaluation of the effectiveness of addition of lime as an agent in stabilizing the waste product like fly ash and its suitability to be used as a construction material for structural fills and embankment materials. Fly ash used for experimentation in this project was collected from the thermal power plant of CPP- NSPCL, Rourkela Steel Plant. For evaluating the suitability of any construction material for various geotechnical engineering works its consistency properties, compaction properties, strength parameters and settlement properties are the most important properties to be tested. In this project, an attempt was made to evaluate the above stated geo-engineering properties of fly ash along with the treated fly ash with different proportion of lime. The overall testing program was conducted in two phases. In the first phase, the physical and chemical characteristics of the fly ash samples were studied by conducting Hydrometer analysis, UCS test, Permeability test and CBR test. In the second phase of the test program, fly ash was mixed with 2%, 4%, 8% and 12% of lime. Lime was added as a percentage of dry weight of Fly ash. The particular UCS samples were cured for 7, 15, 30, and 60 days with varying temperature of 10°C, 25°C, 45°C and 90°C respectively to evaluate the effect of curing temperature on strength of lime stabilized flyash.

1.6 Lime: An Overview

One of the oldest developed construction material is lime i.e. CaO or $Ca(OH)_2$, which is a by-product of burned lime stone (CaCO3), is the oldest urbanized construction materials. Man has been using it for more than 2000 years ago. The Romans had used soil-lime mixtures for construction of roads purposes. However, its utility in the modern geotechnical engineering was limited until 1945, mostly due to the lack of proper understanding of the subject. Today, stabilization of soils or waste materials by lime is being widely used in several constructions such as highways, slope protection, embankments, railways, airports, foundation base, canal lining etc. This is primarily due to the ease of construction, coupled with simplicity of this technology and mostly because it is a cheapest construction material that provides an added attraction for the engineers. Several research works have been reported highlighting the beneficial effect of lime in improving the performance of waste materials. With proper design and construction techniques, lime treatment chemically transforms sustainable waste into usable materials. Lime, either alone or in combination with other materials, can be used to treat a range of soil types.

Stabilization using lime is a long time practice to modify the characteristics of fine grained materials. Lime stabilization occurs in soils containing a suitable amount of clay and the propel mineralogy to produce long-term strength; and permanent reduction in shrinking, swelling and soil plasticity with adequate durability to resist the detrimental effects of cyclic freezing and thawing and prolonged soaking. Lime stabilization occurs over a longer time period of "curing." The effects of lime stabilization are typically measured after 28 days or longer, but can be accelerated by increasing the soil temperature during the curing period. The strength increases with the increase in the lime content up to about optimum lime content. With further increase in the lime content the strength remains constant and at times decreases, causing deleterious effect. The optimum lime content up to which a given fly ash demonstrates increased strength depends on its reactive silica and varies considerably for different fly ashes. Flyashes with insufficient reactive silica show increased strength only with cement and do not generally respond well to lime (Singh and Garg 1999; Antiohos and Tsimas 2004). The strength gained is found to depend on curing period, compactive energy, and water content (Ghosh and Subbarao 2007)

Stabilization occurs when the proper amount of lime is added to a reactive soil. Stabilization differs from modification in a way that a significant level of long-term strength gain is developed through a long-term pozzolanic reaction. However, research has proven that the full term pozzolanic reaction may continue for a very long period of time even many years as long as enough lime is present and the pH remains high (above 10). As a result of this long-term pozzolanic reaction, some soils can show very high strength gain when treated by lime. Very substantial enhancements in shear strength (by a factor of 20 or more in some cases), continuous strength gain with time even after periods of environmental or load damage (autogenously healing) and long-term durability over decades of service even under severe environmental conditions.

1.7 Issues for the Millennium

As per the current records, ash generation in India is approximately 112 million metric tons and its present utilization is only about 42 million metric tons (38% of ash generated). Rest of the unutilized ash is forced to be disposed of on to the ash ponds. Disposal of this huge amount of fly ash faces problems of enormous land requirement, transportation, ash pond construction and also its maintenance. Also in order to meet the rising energy demand power generating industries in India is growing rapidly. According to the future prospects, India shall continue to depend on coal as the prime source of energy. In India environmental issues have become a major concern in the 21st century and hence the solid waste management for coal based thermal power plants shall continue to be a major area of priority. In developing countries like ours, where the problems like increasing population, scarce natural resources specifically land, increasing urbanization and energy requirements goes side by side with the development, it is almost impossible for power generation sector to function in isolation. So now-a- day's use of resource material like Fly ash became a major area of research in the construction field. The past years have witnessed a significant growth in the technology with respect to disposal of fly ash & its utilization in the country and in the next millennium fly ash in itself is going to emerge as a major industry.

1.8 Use of Fly ash

Some of the application areas of Fly ash are given below.

- Manufacture of Portland cement.
- Embankments and structural fill.
- Waste stabilization and solidification.
- Mine reclamation.
- Stabilization of soft soils.
- Road sub base.
- Manufacture of bricks
- Aggregate.
- Flow able fill.
- Mineral filler in asphaltic concrete.
- Application on rivers to melt ice.
- Used as a sub-base product in pavement design.
- Other applications include cellular concrete, geo polymers, & roofing tiles

2.1 Introduction

The coal reserve of India is estimated to be approximately around 200 billion metric tons. Due to this reason, around 90% of the thermal power stations in India are coal based. Total installed capacity of electricity generation is 100,000 MW in India. Out of this, about 73% is from thermal power generation. There are overall 85 coal based thermal and other power stations in our country. The quality of coal found here has a low calorific value of 3,000–4,000 kcal/kg and ash content of it is as high as 35–50%. In order to achieve the required amount of energy production, a high coal fired rate is necessarily required, generating greater ash residue. At present, India produces nearly about 100 million metric tons of coal ash; which is expected to get doubled in the next decade. The most common method as we known adopted in India for the disposal of ashes produced from burning of coal is the wet method. This method requires about 1 acre of land for every 1 MW of installed capacity, apart from a large capital investment which is mandated. Thus, the ash ponds occupy nearly about 26,300 ha of land in India. The utilization of this fly ash in various industries was just mere 3% in 1994, but after growth in the realization about the need for conservation of the environment in India it has gradually been increasing. In 1994, the Government of India had commissioned a Fly Ash Mission (FAM) with the major objective of building belief and confidence among the producers and the consumer agencies about the safe disposal and utilization of fly ash, through technology demonstrated projects. The Fly Ash Mission has so far chosen 10 major areas and has undertaken 55 technology demonstration projects at 21 locations across India. The fly ash utilization has increased from 3% in 1994 to almost 13% in 2002 which is still expected to grow even more. A notification which was issued by the Ministry of Environment and Forests of the Government of India (MOEF 1999) on September 14, 1999, established the basic framework for the advancement in utilization of fly ash and environment conservation efforts to be put in the country. This notification demanded the existing thermal power plants to achieve a total of 20% utilization of fly ash within a span of 3 years and 100% utilization within 15 years. Plants which were newly commissioned were required to achieve 30% utilization of fly ash within the next 3 years and 100% utilization within 9 years. One of the major applications in which fly ash is demanded in large quantities is for the construction purposes of compacted fills and embankments. According to the Electric Power Research Institute's (EPRI) manual (Glogowski et al. 1992) reports, it was stated that a project search conducted in 1984 located 33 embankments and 31 areas fills in North America which were constructed with fly ash. The American Coal Ash Association (ACAA 1999) reported that in 1999 about 33% of the fly ash as well as the bottom ash produced in the United States were used in different applications. The use of fly ash in various structural fills was its second major application (5.1%) next to its use in cement, concrete, and grout (16.1%). Based on a survey conducted on nine thermal power stations, Porbaha et al. (2000) it was estimated that in Japan about 41% of fly ash is used in the Landfills construction. Considering the major role that is played by fly ash in construction of embankments and fills, the Fly Ash Mission in India had adopted this as one of the 10 major areas for technologically demonstrated projects. Already a few demonstrations have been made and embankments have been constructed in India using pond ash (Vittal 2001). The Indian Road Congress had published guidelines for the utilization of fly ash in road embankments (IRC 2001). Fly ash became an attractive construction material because of its self-hardening characteristics which is produced by the available free lime. The variation in its properties depends on the nature of coal, fineness of pulverization, type of furnace used and firing temperature.

2.2 Literatures on Coal Ash and Its Geo-Engineering Properties

Many research works have been done on the properties of fly ash and pond ash by the different researchers for study in their suitability as a construction material in various field of civil Engineering. Some of are summarized below.

Sherwood and Ryley (1970) presented a report on self-hardening characteristics of fly ashes. He said that the presence of free lime in the form of calcium oxide or calcium hydroxide controls the self-hardening characteristics of fly ashes.

Gray and Lin (1972) reported a study on the variation of specific gravity of the coal ash and they showed that the combination of many factors such as gradation, particle shape and chemical composition is responsible for variation in specific gravity.

Mclaren and Digioia(1987) indicated that due to the low specific gravity of coal ash as compared to soils, low dry densities are resulting from ash fills. Because of that it can be used in embankments on weak foundation soils, backfill material for retaining walls, , reclamation of low-lying areas, due to which the pressure exerted on the foundation structure will be less.

Yudbir and Honjo (1991) stated that the self-hardening characteristic is developed due to the presence of free lime content in the fly ash. Depending upon the availability of free lime and carbon contents in the samples in the fly ash, unconfined strength may be achieved as 20 MN/$m_2$in 28m days for some fly ash,while other attain strength in a range of 0.1-0.4 MN/m_2 in 16 weeks.

Rajasekhar(1995) reported that coal ash mainly consists of glassy cenospheres and some solid spheres . The presence of large nnumber of hollow ceno-spheres results in the variation in the chemical composition, in particular iron content in the coal ash and also resulting in low specific gravity of coal ash, from which the removal of entrapped air cannot be possible.

Singh (1996) studied the unconfined compressive strength of fly ashes depends upon the free lime present within them.

Singh and Panda (1996) performed shear strength tests on freshly compacted fly ash specimens at various water contents and concluded that most of the shear strength is due to internal friction.

Pandian and Balasubramanian (1999) showed that co-efficient of permeability of ash depend upon the grain size ,degree of compaction and pozzolanic activity The bottom and pond ashes being coarse grained and devoid of fines compared to fly ash have a higher value for permeability coefficient. The consolidation pressure has negligible effect on the permeability.

Pandian(2004) tried to find out the physical, chemical and engineering properties of flyash by conducting various laboratory experiments for characterization of flyash with reference to geotechnical applications. He found that fly ash is a freely draining material with angle of internal friction of more than 30 degrees with a specific gravity is lower leading to lower unit weights resulting in lower earth pressures. It can be summarized that fly ash (with some modifications/additives, if required) can be effectively utilized in geotechnical applications.

Das and Yudhbir(2005) studied that the geotechnical properties of fly ashes were influenced by the factor like lime content (Cao), iron content (Fe_2O_3), Loss of ignition , morphology, and mineralogy.

Arora and Aydilek (2005) reported a study on investigation of use of classF fly ash amended soil–cement or soil–lime as base layers in highways. A series of tests were carried out on soil–fly ash mixtures which comprised of cement and lime as activators. The test for unconfined compression, California bearing ratio, and resilient modulus tests were performed and he deliberated that strength of a mixture is highly dependent on the curing period, compactive energy, cement content, and water content at compaction.

Kim.et.al (2005) carried out number of experiments on class F flyash and bottom ash for finding out the mechanical properties compaction, permeability, strength, stiffness, and compressibility. they prepared Three mixtures of fly and bottom ash with different mixture ratios i.e. 50, 75, and 100% fly ash content by weight for performing the test.they found that ash mixtures posses good agreement with the conventional granular materials. It is shown that the flyash can not only be used as construction material such as highway embankment fillings but also it can be used as an alternative of the traditional material.

Ghosh and Subbarao (2007) presented the shear strength characteristics of a low lime class F fly ash modified with lime alone or in combination with gypsum. Numbers of experiments were carried out for finding out the unconfined compression strength for both unsoaked and soaked specimens cured up to 90 days. The gain in shear strength of modified fly ash was obtained by adding a small percentage of gypsum 0.5 and 1.0% along with lime (4–10%) within short curing periods 7 and 28 days. For addition of 10% lime along with 1% gypsum to the fly ash, the gain in unsoaked unconfined compressive strength q_u of the fly ash was found to be 2,853 and 3,567%, respectively, at 28 and 90 days curing. Depending on mix proportions and curing period, there duction of qu was varying from 30 to 2% which was the effect of 24 h soaking. Experiments were carried out for the measurements of unconsolidated undrained triaxial tests with pore-pressure for 7 and 28 days cured specimens. With addition of 10% lime along with 1% gypsum to the fly ash the cohesion of the Class F fly ash was increased up to 3,150% and cured for 28 days. They highlighted the effects of lime content, gypsum content, and curing period on the shear strength parameters of the fly ash. To estimate the design parameters like deviatric stress at failure, and cohesion of the modified fly ash the empirical relationships were proposed. With this they conclude that this modified material with improved engineering characteristics may be helpful in different field of civil engineering.

Maitra et al. (2010) observed the reaction between fly ash and lime in fly ash–lime under water curing and steam curing conditions. They collected the fly ash from different courses, characterized, mixed with lime in different ratios and compacted. The compacted fly ash was cured under both water steam condition separately. They considered the reduction in the free CaO content in the compacted fly-ash as a function of curing lime and curing process. By measuring the free lime content the reaction between the flyash and lime was investigated. By determining the reaction order and rate constants with respect to the free CaO content kinetics of these reactions was studied and it was observed that the reaction kinetics was affected by curing conditions and additives significantly.

Reddy and Gourav(2011) examined the improvements in strength gaining characteristics of lime–fly ash by using an additives like gypsum and under goes through low temperature steam curing. They also discussed the influence of lime–fly ash ratio, steam curing and role of gypsum on gain in strength, and characteristics of compacted lime–fly ash–gypsum bricks. The test result showed that there is an increase in strength with increase in density irrespective of lime content, type of curing and water content in the fly ash. Apart from this the results revealed that in the normal curing conditions optimum lime–fly ash ratio yielding maximum strength is about 0.75 and at 80^0 C, 24 h of steam curing is sufficient to achieve nearly possible maximum strength. They even stated that under ambient temperature conditions the pozzolanic reactions of lime take place at a slow pace and hence it requires very long curing durations to achieve meaningful strength values.

Singh and Sharan (2013) showed the effect of compaction energy and degree of saturation on strength characteristics of compacted pond ash. Here the pond ash sample was subjected to compactive energies varying from 357 kJ/m3 to 3488 kJ/m3 which were being collected from ash pond of Rourkela Steel Plant (RSP). By conventional compaction tests they found out The optimum moisture content and maximum dry densities corresponding to different compactive energies. The compaction characteristics of the specimen were assessed for different dry densities and moisture content. They reported that by controlling the compactive energy and moulding moisture content, the dry density and strength of the compacted pond ash can be suitably modified. In this study they ended up with a conclusion that pond ash can replace the natural earth materials in geotechnical constructions as the strength achieved by the pond ash in this test was as good as a similar graded conventional earth materials.

2.3 Literature on Stabilized Flyash

Lavand and AysenLav (2000) carried out a study on micro structural, chemical, mineralogical, and thermal analysis on fly ash as pavement base material. They stabilized the fly ash with lime as well as with the cement separately. The stabilization effect of both lime and cement were studied in terms of chemical composition, crystalline structures, and hydration products. They measured the unconfined compressive strength of samples to detect the effect of stabilization over time. The results obtained from both cement and lime stabilized samples showed that the hydration products that account for gain in strength were almost same for both the stabilizing agents. The proportion and density of these products are responsible for the differences in the result on their strengths.

Ghosh and Subbarao (2001) studied the SEM (Scanning electron microscope) of modified fly ash specimen and it was shown that a compact matrix was produced by the addition of lime to fly ash and to achieve more compact structure as long curing period is necessary. The formation of a densified interlocking network of reaction products is prominent for the mixes containing gypsum, cured for 10 months at 307°C. Depending on the mix proportions and curing period the Ca to Si ratio obtained from the EDAX analysis varies with the value ranges from 1.690 to 0.224. This variation may be accredited to the formation of different hydration products. due to pozzolanic reaction for the specimens stabilized with high lime (10%) and gypsum (1%) formed a complex matrix which was cured for a longer curing period, was responsible for gaining higher strength and durability. Due to the reduction in interconnectivity of the pore channels of the hydration products the permeability had been reduced to 10^{-7} cm/s. in 3 months' curing the strength of fly ash, stabilized with 10% lime and 1% gypsum, had been reached a value of 6,307 kPa, i.e., 36.7 times the strength of fly ash with zero percent additive. With this they conclude that this modified material with improved engineering characteristics may be helpful in different field of civil engineering.

Ghosh and Subbarao (2007) studied the stabilization of low lime fly ash with lime and gypsum through large scale tests on the stabilized material designed to simulate field recycling conditions as thoroughly as possible. It was found to be a very effective means to control hydraulic conductivity and leachate characteristics. They reported the effects of moulding water content, lime content, gypsum content, curing period, and flow period on hydraulic conductivity, and on leachate of metals flowing out of the stabilized fly ash. The values of hydraulic conductivity on the order of 10-7 cm/s were achieved with the help of proper proportioning of the mix, and adequate curing. The concentrations of As, Cd, Cr, Cu, Fe, Hg, Mg, Ni, Pb, and Zn in the effluent emanating from the hydraulic conductivity specimens of mixes with higher proportions of lime or lime and gypsum were found to be below threshold limits which are acceptable for contaminants flowing into ground water.

Ali.et.al (2011)studied the effect of gypsum on the strength development of two Class F fly ashes with different lime contents after curing them for different periods. After soaking the cured specimens in water and with different leachates containing heavy-metal ions the sustainability of improved strength was examined. It was seen that the strength of both the fly ash was improved up to a particular amount of the lime content, which could be considered as optimum lime content, and thereafter the improvement was gradual. They reported that Gypsum accelerates the gain in strength for lime-stabilized fly ashes, particularly in the initial curing periods at about optimum lime content. At low curing periods Gypsum helps in the improvement of reduction in the loss of strength due to soaking and also due to repeated cycles of wetting and drying it improves the durability of stabilized fly ashes.

Reddy and Gourav (2011) studied the lime-pozzolana reaction required very long curing period to achieve appreciable strength under ambient temperature conditions. He examined the improved strength in lime–gypsum-fly ash mixes through low temperature steam curing. A report had been presented where the results of density–strength– moulding water content relationships, influence of lime–fly ash ratio, steam curing and role of gypsum on strength development, and characteristics of compacted lime–fly ash–gypsum bricks were discussed and The test results reveal that (a) strength increases with increase in density irrespective of lime content, type of curing and moulding water content, (b) optimum lime–fly ash ratio yielding maximum strength is about 0.75 in the normal curing conditions, (c) 24 h of steam curing (at 80_C) is sufficient to achieve nearly possible maximum strength, (d) optimum gypsum content yielding maximum compressive strength is at 2%, (e) with gypsum additive it is possible to obtain lime–fly ash bricks or blocks having sufficient strength ([10 MPa) at 28 days of normal wet burlap curing.

2.4 Literature on Curing Temperature

Due to rapid industrialization the generation of fly ash goes on increasing day by day. So disposal of this is a difficult task. Therefore it is used as an alternative of some good conventional construction material. So it is required to know about the influencing parameters such as temperature, moisture content chemical contents etc. of fly-ash. There are many research works are going on effect of moisture and the chemical content present in the flyash on its strength carrying characteristics. But there are very few surveys are done over variation of strength with respect to temperature. So it s required to understand the effect by keeping it in curing temperature condition. Worldwide the variation of temperature is quite high. In some places the temperature even goes to below 0^0C and in some places it goes more than 50^0C. Few researchers have studied the relationship between the strength and soil moisture by varying the temperature. Similarly instead of soil we can use waste material so that it prevents the natural resource with proper disposal of waste material .the pozzolanic reaction of fly ash is strongly influenced by curing temperature and replacement ratio of fly ash momentous gains in the soil strength and modulus were only observed at the higher curing temperature of 50°C,and so it is presumed that for any significant benefits to be gained from soil-lime stabilization work it should be carried out in relatively hot weather. For study in their appropriateness as a construction material in various field of civil Engineering. Few are summarized below.

George et al. (1992) found a momentous gains in the soil strength and modulus were only observed at the higher curing temperature of 50°C, and so it is presumed that for any significant benefits to be gained from soil-lime stabilization work it should be carried out in relatively hot weather.

Maitra.et al. (2009) studied the hydrothermal condition for cured samples of flyash and lime .he found that the rate of decrease in free lime content in water cured compacts was maximum up to 50–55 days of curing and in case of steam curing the rate of decrease was maximum up to a curing period of 10 h. MgCl2 and FeCl3 were used as additives for the compacts made by hydrothermal curing Up to a period of 4 h the additives exhibited no significant effect on the reaction. But afterwards the additives improved the rate of reaction between fly ash and lime, which was evident from a higher drop in free CaO content in the compacts with the additives. MgCl2 exhibited better effect in improving the rate of reaction between fly ash and lime.

Narmluk and Nawa (2014) discussed the degree of pozzolanic reaction of fly ash cured at different temperature .he reported the effect of curing temperature on pozzolanic reaction by using modified Jander's model and the results confirm that the pozzolanic reaction of fly ash is strongly influenced by curing temperature and replacement ratio of fly ash. The higher the curing temperature and the lower the fly ash replacement ratio, the higher is the degree of pozzolanic reaction of fly ash. The rate and mechanism of pozzolanic reaction of fly ash vary with curing temperature. Elevated curing temperatures lead to faster the onset and accelerated the rate of the main reaction linearly.

2.5 SCOPE AND OBJECTIVE OF THE PRESENT WORK

Going through the available literature it is observed that the ash production is continuing to increase in coming years which needs large storing area creating a problem for its economical disposal and causes associates environment hazards .A bulk utilization of flyash is only possible in civil construction fields as a replacement to natural earth material as its properties very closely resembles that of the natural earth. However the stabilization of ash is needed as the compacted un-stabilized flyash is found to reduce its strength substantially on saturation. A number of researches has already being undertaken to evaluate the effect of stabilizing agent like cement and lime on strength properties of flyash .however the effect of curing conditions like curing temperature, curing period and curing environment has not being addressed, upon by the previous researchers keeping this in mind the present work aims at investigating the following aspects of lime stabilized flyash.

- Effect of lime content and curing period on unconfined compressive strength.
- Effect of curing temperature on strength
- Effect of curing environment that is method of curing on strength.
- Effect of lime content and curing period on both soaked and unsoaked CBR values.

EXPERIMENTAL PROGRAMME

3.1 Introduction

Main concern of coal based thermal power plants is Safe and economic disposal of flyash. The problems faced by the thermal power plants for disposal of flyash can be reduced by utilizing flyash significantly in geotechnical construction like highway and railway embankment, landfill, road bases and sub-bases etc. construction in civil engineering field is gaining momentum as it proves to be an effective and efficient means of bulk utilization of waste material like flyash . However compacted ash suffers great loss of shear strength on saturation. So to transform the waste material into safe construction material Stabilization of flyash is required .for increasing use of flyash as a construction material, It is required to evaluate its behaviour at different conditions and enhance some properties before using as a construction material .The tests at laboratory scale provide a measure to control many of the variable encountered in practice as adequate substitute for full scale field tests are not available. In the laboratory tests the trends and behaviour pattern observed to predict the behaviour of field structures. This is helpful for understanding the performance of the structures in the field and may be used in formulating mathematical relationship. In the current work the effect of curing temperature on the strength of lime stabilized flyash has been evaluated through a series of unconfined compression test, proctor compaction and CBR tests. Details of material used, sample preparation and testing procedure adopted have been outlined in this chapter.

3.2 Experimental Arrangements

3.2.1 Materials Used

3.2.1.1 Fly Ash

Fly ash used in this study was collected from the thermal power plant of Rourkela steel plant (RSP).The sample was screened through 2mm sieve to separate out the foreign and vegetative matters. The collected samples were mixed thoroughly to get the homogeneity and oven dried at the temperature of 105-110 degree. Then the Fly ash samples were stored in airtight container for subsequent use.

3.2.1.2 Lime

Lime (Calcium Oxide CaO) used in this study was first sieved through 150 micron sieve and stored in airtight container for subsequent use.

Fig.3.1: Fly ash

Fig.3.2: Lime

Physical Properties of fly ash

The physical properties of the Flyash sample passing through 2mm sieve were determined and are presented in Tables 3.1.

Table 3.1 Physical Properties of flyash

Physical parameters	**Values**	**Physical parameters**	**Values**
Colour	Light grey	Shape	Rounded/sub-rounded
Silt &clay (%)	88	Uniformity coefficient, Cu	5.67
Fine sand (%)	12	Coefficient of curvature, Cc	1.25
Medium sand (%)	0	Specific Gravity, G	2.38
Coarse sand (%)	0	Plasticity Index	Non-plastic

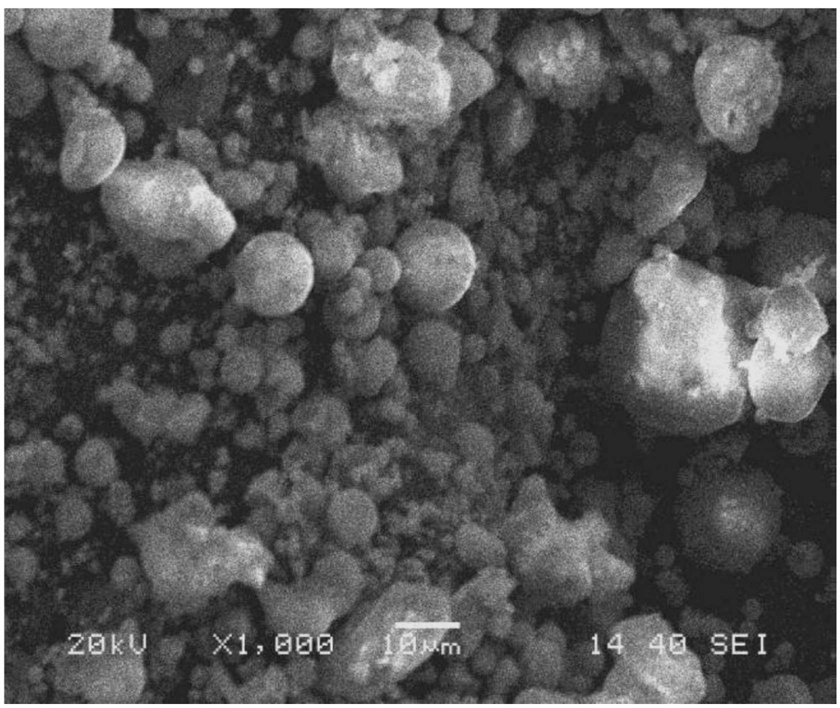


Fig.3.3: Scanning Electron Micrograph (SEM) of flyash

The surface morphology of flyash was studied by using Scanning Electron Microscope. This analysis show that flyash mainly contain angular size particle and have uniform gradation. Micrographs were taken at accelerating voltages of 20 kV for the best possible resolution. Fig 3.3 shows the surface morphology of flyash.

3.2.1.3 Chemical composition of flyash

The chemical compositions of the flyash sample passing through 2mm sieve were determined and are presented in Tables 3.2 and it shows that the flyash merely consists of aluminum oxide and silicon oxide. Apart from these two major particles it contains magnesium (MgO), potassium (K_2O), calcium oxide (CaO).

Table 3.2 Chemical Composition of flyash

Elements	MgO	Al_2O_3	SiO_2	K_2O	P_2O_5	CaO	Fe_2O_3	Na_2O	MnO	TiO_2	Loss on Ignition
Composition (%)	1.7	28.1	53.6	1.97	1.72	2.65	1.8	0.5	0.3	0.85	6.5

3.3 Determination of Index Properties

3.3.1 Determination of Specific Gravity

The specific gravity of flyash was determined according to IS: 2720 (Part-III, section-1) 1980 by using Le-Chatelier flask with Kerosene as the solvent. The specific gravity of flyash was found to be 2.38.

3.3.2 Determination of Grain Size Distribution

Flyash was passed through 75µ size opening test sieve for determination of grain size distribution. For determination of coarser particles Sieve analysis was conducted as per IS: 2720 part (IV), 1975 and for finer particles hydrometer analysis was conducted as per IS: 2720 part (IV). The percentage of flyash passing through 75µ sieve was found to be 88% .Hence the particle size of flyash ranges from fine sand to silt size. Coefficient of uniformity (Cu) and coefficient of curvature (Cc) was found to be 5.67 & 1.25respectively, indicating uniform gradation of samples. The grain size distribution curve of flyash is presented in Fig 4.1

3.4 Determination of Engineering Properties

3.4.1 Moisture Content Dry Density Relationship

The moisture content, dry density relationships were found by using compaction tests as per IS: 2720 (Part VII) 1980. Fly ash was stabilized with varying percentage of lime (0%, 2%, 4%, 8% and 12%) of its dry weight. For this test, flyash was thoroughly mixed with adequate amount of water and the wet sample was compacted in proctor mould either in three or five equal layers using standard proctor rammer of 2.6 kg or modified proctor rammer of 4.5 kg. As per IS: 2720 (Part 2) 1973 the moisture content of the compacted mixture was determined. From the dry density and moisture content relationship, optimum moisture content (OMC) and maximum dry density (MDD) were determined. Similar compaction tests were conducted with varying percentage of lime (0%, 2%, 4%, 8% and 12%) and the corresponding OMC and MDD were determined. This was done to study the effect of lime content and compactive energy on OMC and MDD. The compactive energies used in this test programme 595 and 2483 kJ/m3 of compacted volume. The test results are presented in Table 3.3

Table 3.3.Compaction characteristics of flyash amended with lime.

Lime content (%)	Compactive energy at 593 kJ/m³		Compactive energy at 2483 kJ/m³	
	Maximum dry density, MDD (g/cc)	Optimum moisture content, OMC (%)	Maximum dry density, MDD (g/cc)	Optimum moisture content, OMC (%)
0	1.12	40.5	1.236	33
2	1.085	43	1.206	35.8
4	1.089	42	1.237	35
8	1.097	41.5	1.244	34.8
12	1.108	41.3	1.25	34.5

3.4.2 Determination of Unconfined Compressive Strength

The Unconfined compressive strength test is one of the common tests used to study the strength characteristics of soil and stabilized soil. For testing fly ash and lime stabilized fly ash specimens were compacted to their corresponding MDD at OMC with compactive energy varying as 593 and 2483 kJ/m3 according to IS: 2720 (Part X). The cylindrical test specimens were of size 50 mm in diameter and 100 mm in height were sheared at an axial strain rate of 1.25 mm/min till failure of the sample. Samples were prepared in two ways i.e. sealed and unsealed. Sealed samples were coated with wax to maintain the actual moisture and unsealed samples were made without any coating to check strength variation between two. To evaluate the effects of curing temperature on strength properties of sealed and unsealed UCS samples the specimen were cured at a temperature of 10°C, 25°C, 45°C and 90°C with a curing periods of 0, 7, 15, 30, and 60 days before testing . For each lime content and curing period three identical specimens were tested and the average value was reported.

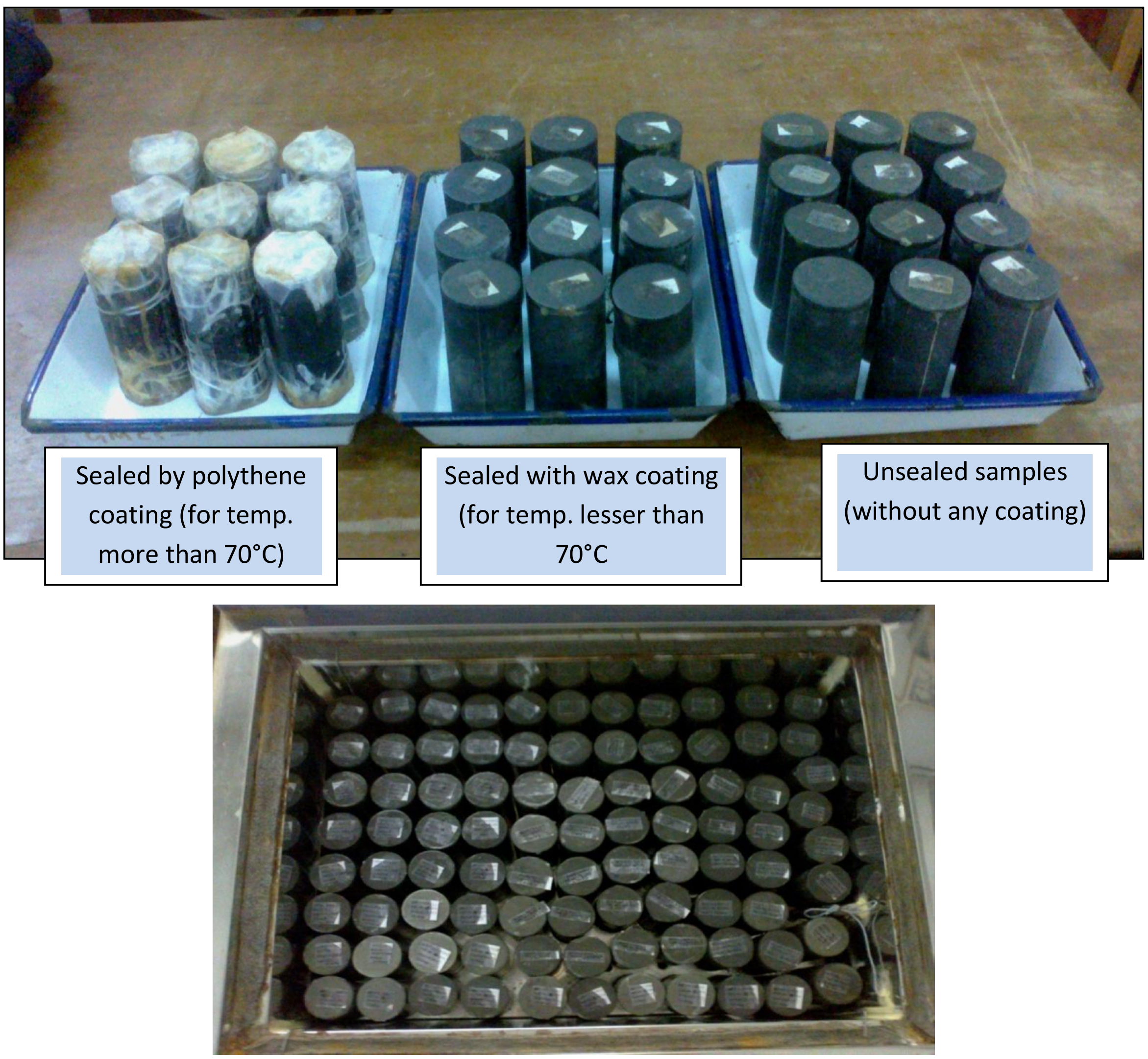


Fig 3.4: samples are cured at different temperature with wax coating

Fig 3.5: before testing of (UCS sample)

Fig 3.6 after testing (UCS sample)

The unconfined compressive strengths of specimens were determined from stress versus strain curves and the failure stress and corresponding failure strain at 10°C, 25°C, 45°C, and 90°C temperature with 0, 7, 15, 30 and 60 days of curing at a compactive energy of 595 kJ/m3 and 2853 kJ/m3 is given in Table, 3.4, 3.5, 3.6, 3.7, 3.8, 3.9, 3.10, 3.11, 3.12, 3.13, 3.14, and 3.15.

Table 3.4: Unconfined compressive strength of lime-fly ash mixes compacted with 595 kJ/m^3 energy and cured at temperature 10°C (sealed samples)

Lime content (%)	Immediate		7days		15 days		30 days		60 days	
	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %
0	184.21	2.75	190.30	3.00	214.48	3.00	239.80	2.75	280.66	3.25
2	261.52	2.75	315.76	2.75	340.56	2.25	426.44	2.00	441.77	1.75
4	312.50	2.75	450.67	2.75	453.47	2.5	533.05	2.00	630.93	2.25
8	348.53	3.25	506.24	2.5	625.01	2.75	1117.22	2.5	1767.75	2.50
12	354.36	3.00	539.33	2.75	738.24	3.00	1739.47	2.5	2856.69	2.50

Table 3.5: Unconfined compressive strength of lime-fly ash mixes compacted with 2483kJ/m^3 energy and cured at temperature 10°C (sealed samples)

Lime content (%)	Immediate		7days		15 days		30 days		60 days	
	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %
0	375.38	3.5	383.97	3.25	401.49	3.5	513.54	3.00	547.30	3.25
2	536.95	3.5	631.30	2.75	695.59	3.00	758.54	2.25	843.60	2.25
4	625.09	4.00	665.43	3.00	919.74	3.75	1060.65	2.5	1130.06	2.00
8	691.66	4.00	940.40	3.00	1282.66	4.00	1969.73	3.00	2121.3	2.50
12	836.66	4.5	1105.15	3.5	1601.59	3.75	2946.98	3.25	3723.92	2.75

Table 3.6: Unconfined compressive strength of lime-fly ash mixes compacted with 2483kJ/m^3 energy and cured at temperature 10°C (unsealed samples)

Lime content (%)	Immediate		7days		15 days		30 days		60 days	
	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %
0	375.38	3.5	411.39	3.25	506.07	3.5	575.95	3.25	596.41	3.25
2	536.95	3.5	767.93	3.25	770.67	3.25	808.41	3.00	909.82	2.75
4	625.09	4.00	835.91	3.00	948.65	3.00	1086.13	3.00	1195.91	3.00
8	691.66	4.00	990.26	3.5	1371.31	3.25	2136.26	4.00	2532.51	3.00
12	836.66	4.5	1148.92	3.5	1691.63	3.75	3367.97	3.25	4556.16	2.75

Table 3.7: Unconfined compressive strength of lime-fly ash mixes compacted with 595 kJ/m^3 energy and cured at temperature 25°C (sealed samples)

Lime content (%)	Immediate		7days		15 days		30 days		60 days	
	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %
0	190.21	2.75	200.94	2.5	222.21	2.5	272.56	3.00	307.97	3.00
2	290.60	2.5	355.36	2.25	371.30	2.00	443.14	2.25	450.34	2.75
4	320.5	2.75	465.70	2.00	472.35	2.00	550.26	2.75	648.93	3.00
8	360.53	3.25	829.16	2.25	1155.30	2.5	1215.74	2.75	1777.75	3.25
12	372.35	3.00	1209.87	2.75	1885.64	2.75	2207.80	3.25	3077.45	2.00

Table 3.8: Unconfined compressive strength of lime-fly ash mixes compacted with 2483 kJ/m^3 energy and cured at temperature 25°C (sealed samples)

Lime content (%)	Immediate		7days		15 days		30 days		60 days	
	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %
0	395.57	3.25	406.96	3.00	412.17	3.25	530.20	3.75	550.94	3.00
2	551.84	3.25	694.43	2.75	750.66	3.25	800.06	3.25	850.60	2.5
4	639.09	3.5	860.117	2.75	968.73	2.5	1100.81	3.75	1160.81	2.5
8	712.12	4.00	1541.57	3.75	1694.30	2.25	2019.04	3.5	2379.91	3.25
12	860.65	4.5	2032.69	3.75	2475.16	2.00	3475.16	2.75	4408.05	2.5

Table 3.9: Unconfined compressive strength of lime-fly ash mixes compacted with 2483 kJ/m^3 energy and cured at temperature 25°C (unsealed samples)

Lime content (%)	Immediate		7days		15 days		30 days		60 days	
	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %
0	395.57	3.5	426.20	3.00	493.46	2.75	588.90	2.5	610.81	2.75
2	551.84	3.25	785.43	3.75	792.85	3.25	800.06	3.00	990.82	3
4	639.09	3.5	860.11	2.75	970.67	3.00	832.24	2.5	1200.90	2.75
8	712.12	4.00	1392.99	2.5	1779.30	3.25	1165.81	2.25	2220.95	3.5
12	860.65	4.25	1866.75	2.5	2220.95	4.00	2195.40	2.25	4558.15	3.00

Table 3.10: Unconfined compressive strength of lime-fly ash mixes compacted with 595 kJ/m^3 energy and cured at temperature 45°C (sealed samples)

ime content (%)	Immediate		7days		15 days		30 days		60 days	
	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %
0	195.64	2.75	205.64	2.5	224.21	2.5	291.26	2.5	310.96	3.00
2	290.84	2.75	361.43	2.25	373.36	2.00	443.14	2.25	453.93	2.75
4	322.50	2.75	469.48	2.00	480.35	2.25	594.23	3.00	655.03	3.00
8	364.80	3.25	974.79	2.25	1188.46	2.5	1297.67	3.00	1891.15	2.75
12	384.94	3.00	1654.07	2.5	2131.02	3.00	3181.95	2.5	2900.93	3.00

Table 3.11: Unconfined compressive strength of lime-fly ash mixes compacted with 2483 kJ/m^3 energy and cured at temperature 45°C (sealed samples)

Lime content (%)	Immediate		7days		15 days		30 days		60 days	
	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %
0	395.57	3.75	410.95	3.00	413.18	3.5	535.2	3.75	560.94	3.25
2	551.84	3.75	696.43	2.75	755.86	3.25	805.01	3.25	860.94	3.00
4	639.09	3.75	862.43	2.75	972.82	3.00	1188.55	4.00	1814.34	3.25
8	712.12	4.25	1167.77	3.00	2877.21	3.00	3167.81	2.5	3462.96	2.75
12	860.65	4.75	3266.80	2.5	3402.79	2.25	3575.80	3.25	4513.84	2.75

Table 3.12: Unconfined compressive strength of lime-fly ash mixes compacted with 2483 kJ/m3 energy and cured at temperature 45°C (unsealed samples)

Lime content (%)	Immediate		7days		15 days		30 days		60 days	
	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %
0	395.57	3.5	428.95	3.00	519.07	3.5	589.0	3.75	612.00	3.25
2	551.84	3.5	788.84	3.00	798.30	3.5	835.0	3.25	992.48	2.25
4	639.09	3.5	879.90	3.00	992.48	2.25	1192.56	3.00	1914.34	3.25
8	712.12	3.75	1870.46	3.25	2286.43	3.75	3296.26	2.5	3496.27	3.00
12	860.65	4.25	3582.86	2.75	4678.10	3.00	5472.81	3.25	7294.47	3.75

Table 3.13: Unconfined compressive strength of lime-fly ash mixes compacted with 595 kJ/m3 energy and cured at temperature 90°C (sealed samples)

Lime content (%)	Immediate		7days		15 days		30 days		60 days	
	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %
0	195.64	2.75	248.11	2.75	319.79	2.75	343.71	3.00	355.18	3.25
2	290.84	2.75	363.11	2.5	379.88	2.00	448.81	2.25	460.98	2.5
4	322.50	2.75	621.08	1.75	647.28	2.00	682.36	1.75	713.96	2.00
8	364.80	3.25	2191.64	2.75	2273.87	2.00	2304.27	2.00	2460.98	2.75
12	384.94	3.00	4041.51	2.25	4475.83	2.25	5479.07	2.00	5951.39	3.00

Table 3.14: Unconfined compressive strength of lime-fly ash mixes compacted with 2483 kJ/m3 energy and cured at temperature 90°C (sealed samples)

Lime content (%)	Immediate		7days		15 days		30 days		60 days	
	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %
0	395.57	3.5	523.79	2.75	514.19	3.00	580.2	3.00	606.49	2.75
2	551.84	3.5	698.48	2.75	800.86	3.25	850.10	3.25	905.94	2.25
4	639.09	3.5	1151.96	1.75	1366.60	3.00	1416.09	3.00	1900.15	3.25
8	712.12	3.75	3965.18	1.75	4535.65	2.00	4708.15	3.00	5066.97	2.25
12	860.65	4.25	6925.67	3.25	7280.19	2.5	7905.92	2.5	8396.44	3.75

Table 3.15: Unconfined compressive strength of lime-fly ash mixes compacted with 2483 kJ/m3 energy and cured at temperature 90°C (unsealed samples)

Lime content (%)	Immediate		7days		15 days		30 days		60 days	
	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %	Failure stress(σ) in kPa	Failure strain(ε) in %
0	395.57	3.5	474.90	3.00	520.60	3.00	590.8	3.00	625.32	2.75
2	551.84	3.5	790.50	3.00	805.32	3.25	860.31	3.25	999.30	2.25
4	639.09	3.5	1182.82	1.75	1400.98	3.00	1499.79	2.00	1932.83	3.25
8	712.12	3.75	4312.30	3.00	4793.96	3.25	5103.17	2.25	5139.36	2.25
12	860.65	4.25	7052.73	4.00	7295.74	2.5	9206.36	3.25	9813.80	3.5

3.4.3 Determination of California Bearing Ratio

One of the essential parameter, used in the evaluation of soil sub grades for both rigid and flexible pavement design is bearing ratio. It is also a primary part of numerous pavement thickness design Methods. To evaluate the suitability of Fly ash and lime-stabilized flyash both in soaked and unsoaked condition, the CBR tests have been conducted in accordance with IS: 2720(Part XVI)-1987. For this test specimens were prepared in a rigid metallic cylindrical mould with an inside diameter of 150 mm and a height of 175 mm to their MDD at OMC. Static compaction is done by keeping the mould assembly in compression machine and compacted the sample by pressing the displacer disc till the level of the disc reaches the top of the mould. The load was kept for some time, and then release. The displacer disc was removed .The mould with samples were tested in a CBR testing machine. A mechanical loading machine equipped with a movable base that moves at a uniform rate of 1.2 mm/min and a calibrated proving ring is used to record the load. The proving ring is attached with a piston, which penetrates into the compacted specimen. Diameter of the piston is 50 mm .The load was recorded carefully as function of penetration up to a penetration of 12.5 mm.

To study the effect of curing period the fly ash and lime stabilized Fly ash samples with different percentage of lime (0%, 2%, 4%, 8%, and 12%) were prepared at a MDD and OMC corresponding to the compaction energy of 593 and 2483 kJ/m^3.To study the effect of pozzolanic reaction of lime on CBR value of stabilized fly ash these samples were subjected to a curing period of 7 days and 30 days for a soaking period of 4 days for soaked samples as shown in figure 3.7(i)-3.7(ii).

Fig 3.7(i): Lime treated fly ash sample subjected to 7 days of curing period

Fig 3.7(ii): Lime treated fly ash sample subjected to 30 days of curing period

Fig 3.8: testing of CBR

The Soaked and unsoaked CBR value of all samples at different compaction energy are given in the table 3.16, 3.17, 3.18 and 3.19.

Table 3.16: CBR test result of Fly ash and lime treated Fly ash at 7 days of curing with compactive energy of 595 kJ/m^3

Lime content in %	Soaked CBR value		Unsoaked CBR value	
	CBR Value at 2.5 mm Penetration(%)	CBR value at 5mm Penetration (%)	CBR Value at 2.5 mm Penetration(%)	CBR value at 5mm Penetration(%)
0	1.3	1.2	24.89	24.53
2	33.9	32.3	38.8	38.5
4	39.3	38.8	41.27	41.00
8	44.2	43.9	55.03	52.33
12	53.4	51.8	63.93	62.04

Table 3.17: CBR test result of Fly ash and lime treated Fly ash at 30 days of curing with compactive energy of 595 kJ/m3

Lime content in %	Soaked CBR value		Unsoaked CBR value	
	CBR Value at 2.5 mm Penetration(%)	CBR value at 5mm Penetration (%)	CBR Value at 2.5 mm Penetration(%)	CBR value at 5mm Penetration(%)
0	2.5	2.4	26.71	25.90
2	44.5	43.2	45.32	42.08
4	61.5	59.9	63.13	57.73
8	117.4	112.8	121.40	113.30
12	165.1	162.4	180.48	174.27

Table 3.18: CBR test result of Fly ash and lime treated Fly ash at 7days of curing with compactive energy of 2483 kJ/m3

Lime content in %	Soaked CBR value		Unsoaked CBR value	
	CBR Value at 2.5 mm Penetration(%)	CBR value at 5mm Penetration (%)	CBR Value at 2.5 mm Penetration(%)	CBR value at 5mm Penetration(%)
0	5.8	5.7	72.8	71.2
2	86.6	83.1	91.5	87.4
4	105.2	104.1	110.1	105.2
8	109.3	105.2	118.2	109.0
12	113.3	108.4	135.2	133.8

Table 3.19: CBR test result of Fly ash and lime treated Fly ash at 30 days of curing with compactive energy of 2483 kJ/m3

Lime content in %	Soaked CBR value		Unsoaked CBR value	
	CBR Value at 2.5 mm Penetration(%)	CBR value at 5mm Penetration (%)	CBR Value at 2.5 mm Penetration(%)	CBR value at 5mm Penetration(%)
0	12.1	11.3	75.3	74.5
2	89.0	80.9	95.5	90.6
4	128.7	121.9	139.2	136.5
8	153.0	151.6	195.9	194.8
12	279.2	262.8	290.5	288.7

3.4.4 Determination of Permeability

The permeability of fly ash is determined according to IS: 2720 (Part XVII)-1986. For evaluating hydraulic conductivity, test samples were prepared corresponding to their MDD at OMC in a permeability mould having diameter 10cm × height 12.5cm with 595 and 2483 kJ/m3 of compaction energy. However the Lime stabilized samples was subjected to a curing period of 7 days, 15 days and 30 days at moist environment to maintaining its moisture content for proper curing. Constant head permeability test was run and the coefficients of permeability were determined. Values of coefficient of permeability of these samples are presented in Table. 3.20.

Fig 3.9 cured permeability samples

Fig 3.10: Constant head permeability test

Fig 3.11 Constant head permeameter

Table 3.20: Co-efficient of permeability of lime stabilized flyash with different curing period at compactive energy 593kJ/m3 and 2483kJ/m3

samples	Coefficient of permeability(k) at different compaction energy (cm/sec)					
	7 day		15 days		30 days	
	$593 kJ/m^3$	$2483 kJ/m^3$	$593 kJ/m^3$	$2483 kJ/m^3$	$593 kJ/m^3$	$2483 kJ/m^3$
FA+0%L	5.31×10^{-5}	3.91×10^{-5}	2.5×10^{-5}	1.605×10^{-5}	1.34×10^{-5}	1.31×10^{-5}
FA+2%L	4.65×10^{-5}	2.32×10^{-5}	2.105×10^{-5}	1.98×10^{-5}	1.20×10^{-5}	1.16×10^{-5}
FA+4%L	3.04×10^{-5}	1.44×10^{-5}	6.72×10^{-6}	3.97×10^{-6}	3.88×10^{-6}	3.67×10^{-6}
FA+8%L	2.26×10^{-5}	0.98×10^{-5}	2.91×10^{-6}	2.44×10^{-6}	2.42×10^{-6}	2.34×10^{-6}
FA+12%L	1.58×10^{-5}	0.474×10^{-5}	2.01×10^{-6}	1.23×10^{-6}	1.02×10^{-6}	1.00×10^{-6}

RESULTS AND DISCUSSION

4.1 General

Fly ash is a fine residues generated due to combustion of coal, and comprises of very fine particles that rise with the flue gases. This material is solidified while suspended in exhausted and captured by electrostatic precipitators or other particle filtration equipment before the flue gases reach the chimneys of coal fired power plants. Fly ash generally contains spherical shape particles. Fly ash consists of inorganic matter present in the coal that has been fused during coal combustion. On compacted fly ash specimen a series of traditional laboratory tests are being carried out such as light and heavy compaction tests, unconfined compressive strength tests, CBR tests and permeability test .these test results are presented and discussed in this chapter.

4.2 Index Properties

4.2.1 Specific Gravity

According to IS: 2720 (Part-III, section-1) 1980the specific gravity of fly ash was determined and found to be 2.38guidelines by Le-Chartelier method with kerosene oil. Specific gravity is one of the important physical properties needed for the use of coal ashes for geotechnical and other applications. In coal ash the variation of specific gravity occurs due to combination of many factors such as gradation, particle shape and chemical composition. The specific gravity of fly ash is found to be lower than that of the conventional earth material and it depend on the source of coal, degree of pulverization and firing temperature. The reason for a low specific gravity could either be due to the presence of large number of hollow cenospheres from which the entrapped micro bubbles of air cannot be removed, or the variation in the chemical composition, in particular iron content, or both .In general, coal ashes having specific gravity lies around 2.0 but it can be vary to a larger extent (1.6 to 3.1). The presence of foreign materials in the fissures of the coal seams mostly influences the specific gravity of resulting flyash.

4.2.2 Grain Size Distribution

Mostly the particles present in Fly ash ranges from fine sand to silt size as shown in Fig. 4.1. The percentage of Fly ash passing through 75μ sieve was found to be 88%. The uniformity coefficient (Cu) and coefficient of curvature (Cc) for Fly ash were found to be 5.67 & 1.25 respectively, indicating uniform gradation of samples. The grain size distribution mostly depends on degree of pulverization of coal and firing temperature in boiler units. The grain size distribution also affected due to presence of foreign matters in flyash. In ash pond the original particles undergoes flocculation and conglomeration resulting in an increase in particle size.

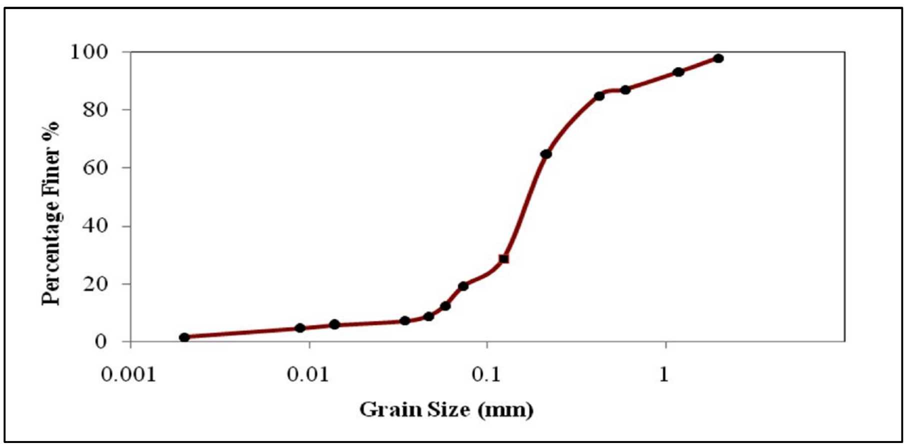


Fig.4.1 Grain size distribution curve of fly ash.

4.3 Engineering Properties

4.3.1 Compaction Characteristics

The compaction characteristics of fly ash with different lime content and varying compaction energies 593 and 2483 kJ/m³ of compacted volume have been studied. The OMC (optimum moisture content) and MDD (maximum dry density) of fly ash and flyash amended with lime samples corresponding to these compactive efforts have been evaluated and presented in fig 4.2, 4.3 and 4.4 .Dry density and moisture content relationship of fly ash at different lime content and compactive energies have been shown in Fig 4.5 and Fig 4.6. It is seen that as the compactive energy increases the MDD increases and the water required to achieve this density is reduced. Initially the addition of lime imparts plasticity to the flyash resulting in marginal decrease in dry density and increase in moisture content values but later on due to more addition of lime results increase in dry density and reduction in moisture content .The MDD of fly ash specimen is found to change from 1.12 to 1.236 g/cc with change in compaction energy from 595 to 2483kJ/m3, and 1.108 to 1.25 g/cc with lime treated flyash at similar compactive energies .whereas the OMC of flyash and flyash amended with lime is found to decrease from 40.5to 33% and 41.3 to 34.5 respectively. This shows that the compacted density of fly ash responds very poorly to the compaction energy. There are many factors like gradation, carbon content, iron content and fineness etc., mainly control the compaction characteristics of fly ash.

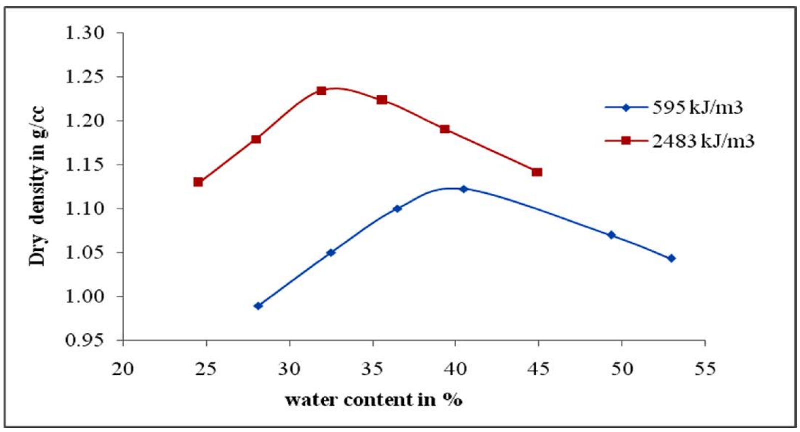


Fig.4.2: Variation of dry density with moisture content of flyash at compaction energy 595kJ/m3 and 2483 kJ/m3.

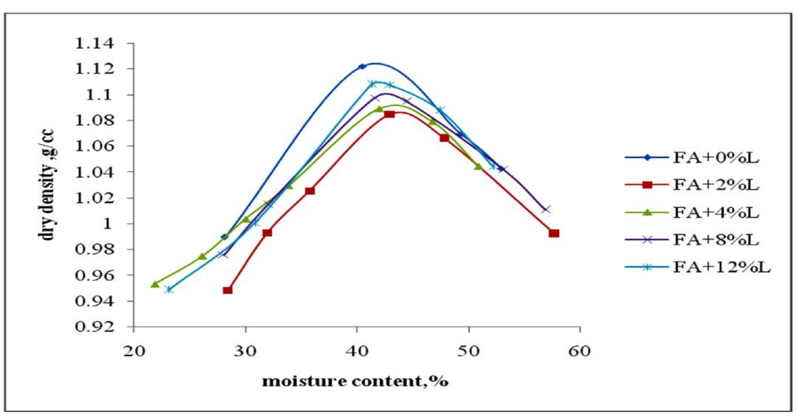


Fig 4.3 Compaction characteristics of flyash amended with lime at compactive energy 595 kJ/m3

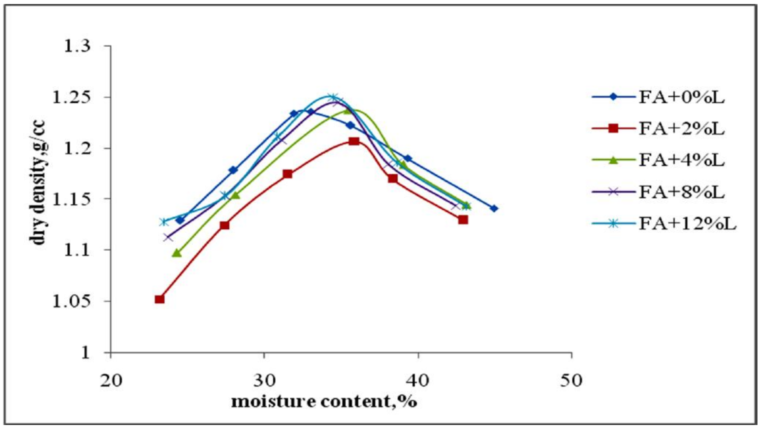


Fig 4.4 Compaction characteristics of flyash amended with lime at compaction energy 2483 kJ/m3

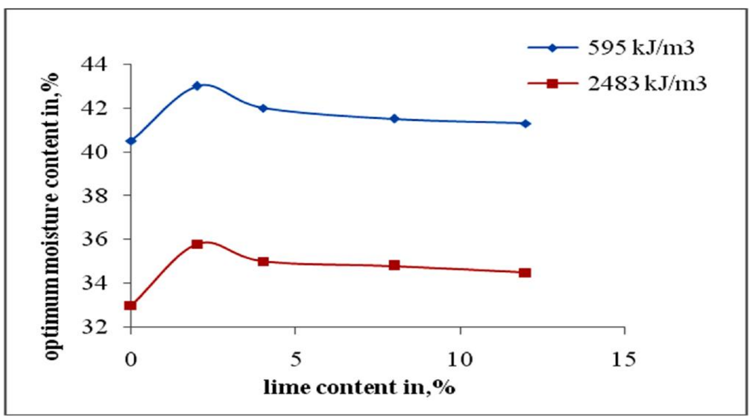


Fig 4.5: Variation of OMC of Fly ash with different lime content and compaction energy 595kJ/m3

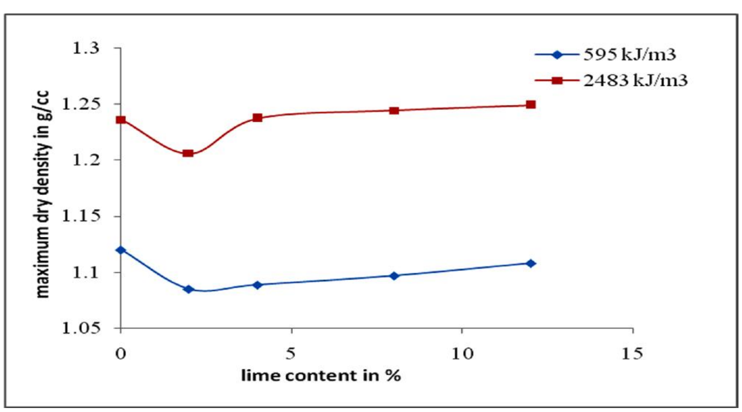


Fig 4.6 Variation of MDD of Fly ash with different lime content and compaction energy 2483kJ/m3

The variation of MDD and OMC with the compaction energy and lime content is shown in figure 4.5 & 4.6.With increase in compaction energy and lime content MDD decreases& OMC increases up to certain stage after that MDD increases and OMC decreases. A linear relationship between OMC, MDD, lime content and compaction energy is found after compaction energy of 595 kJ/m3 and 2483 kJ/m3 with different percentage of lime.

4.3.2 Determination of Unconfined Compressive Strength

4.3.2.1 Effect of Curing condition on lime stabilized flyash

Unconfined compressive strength tests were carried out on treated fly ash specimens compacted to their corresponding MDD at OMC with compactive effort varying as 593 and 2483kJ/m3. The stress-strain relationships of compacted fly ash with curing temperature of 10°C, 25°C, 45°C and 90°C /immediate, 7days, 15days, 30days and 60days were presented in Fig.4.7- Fig.4.18. Form these plots it is observed that the failure stress as well as failure strain of samples compacted with greater compaction energy, are higher than the samples compacted with lower compaction energy. At higher temperature and curing period the unconfined compressive strength give remarkable strength.

The immediate compressive strength of fly ash is 184.21kPa at compaction energy of 595 kJ/m^3 which increases to 375.38kPa at compaction energy of 2483kJ/m^3 at 10°C, similarly immediate compressive strength of fly-ash at 90°C with similar compactive energies are 195.64kPa and 395.57kPa respectively. However in general the failure strains are found to be lower for samples compacted with higher energies. The failure strains vary from a value of 2 to 3.75%, indicating brittle failure in the specimens. The increase in unconfined strength of specimens with increased compactive effort is attributed to the closer packing of particles, resulting in the increased interlocking among particles. A closer packing is also responsible in increasing the cohesion component in the sample.

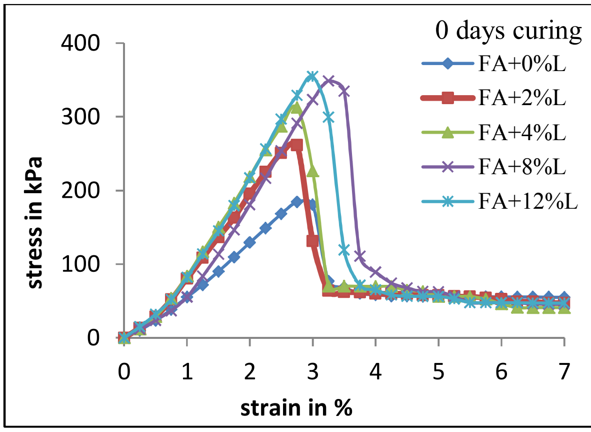


Fig 4.7(i)

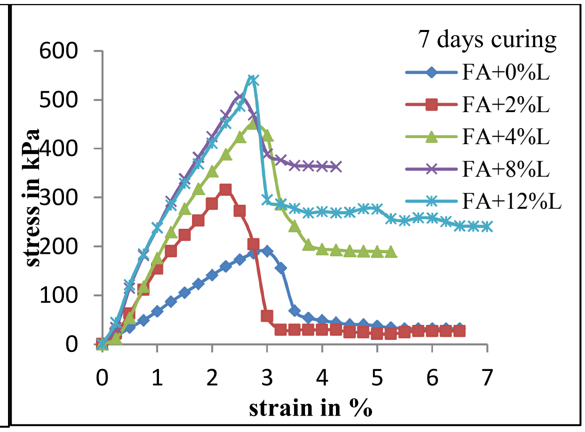


Fig 4.7(ii)

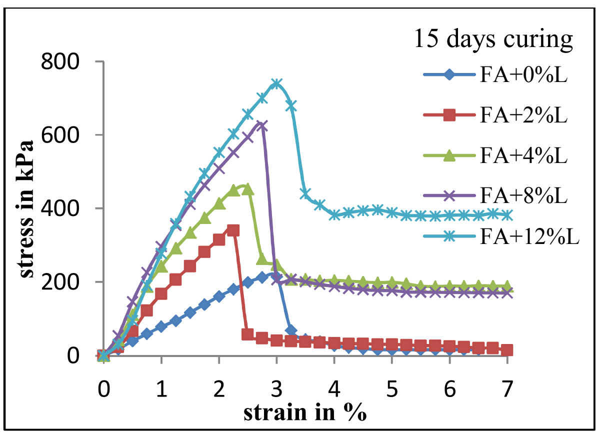


Fig 4.7(iii)

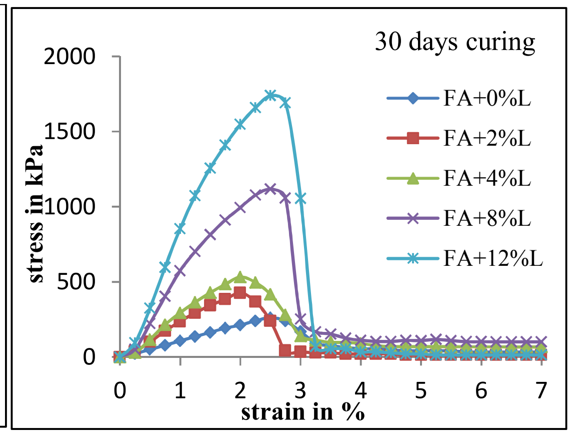


Fig 4.7(iv)

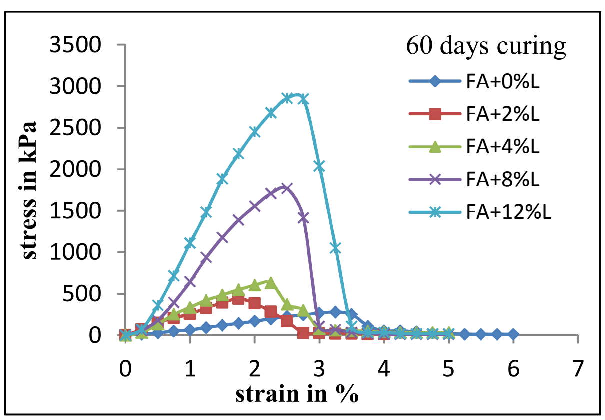


Fig 4.7(v)

Fig 4.7(i) - 4.7(v): Stress~strain curve of stabilized flyash prepared at compactive energy of 595 kJ/m^3 and cured at 10°C temperature (sealed samples)

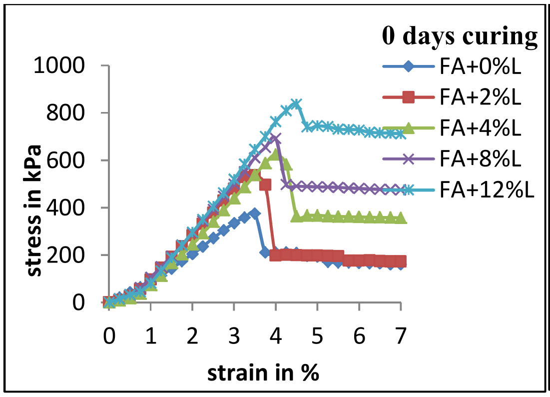


Fig 4.8(i)

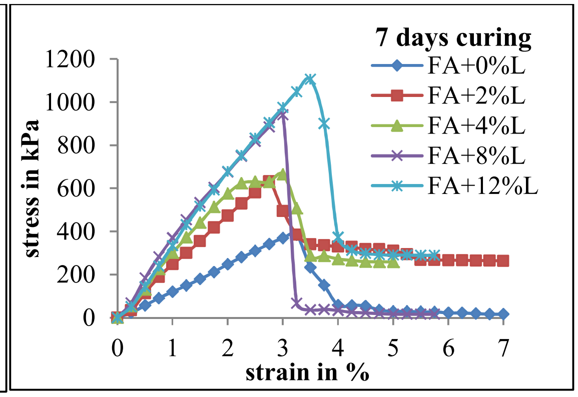


Fig 4.8(ii)

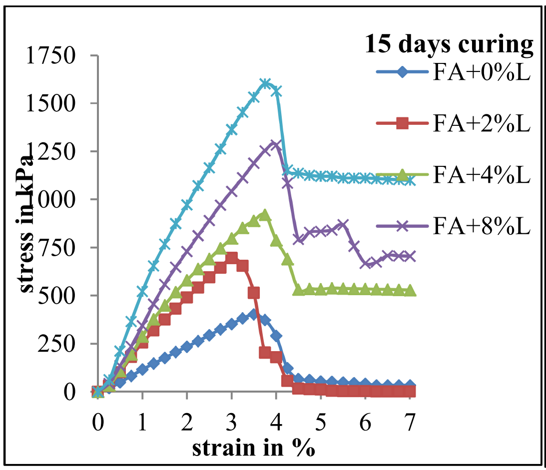


Fig 4.8(iii)

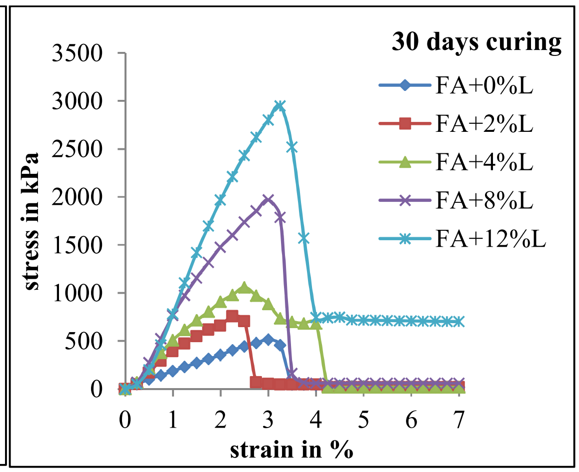


Fig 4.8(iv)

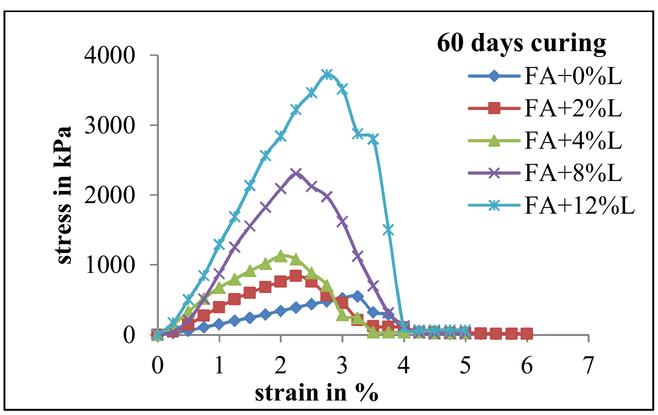


Fig 4.8(v)

Fig4.8(i) - 4.8(v): Stress~strain curve of stabilized flyash prepared at compactive energy of 2483 kJ/m3and cured at 10°C temperature (sealed samples)

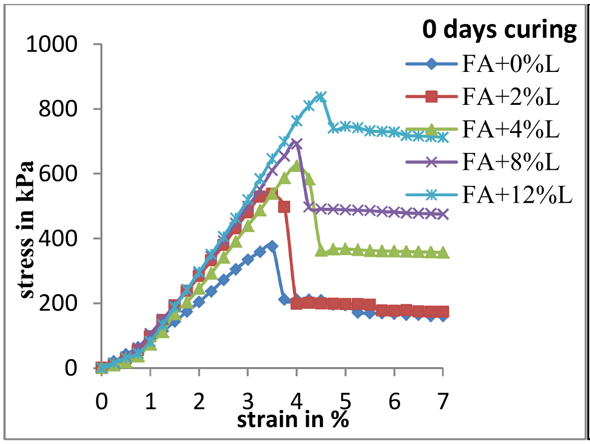


Fig 4.9(i)

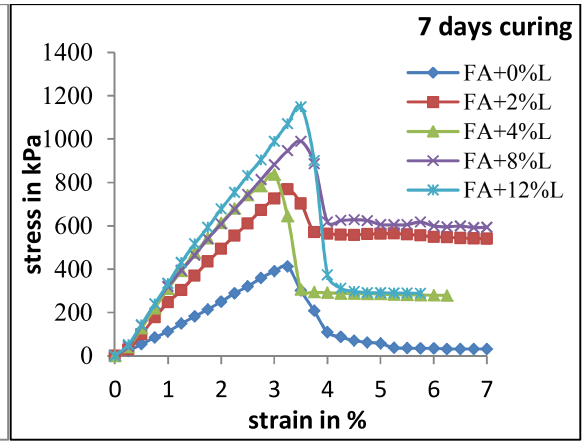


Fig 4.9(ii)

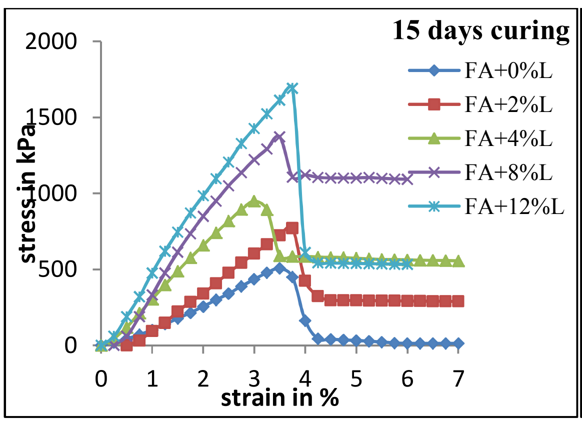


Fig 4.9(iii)

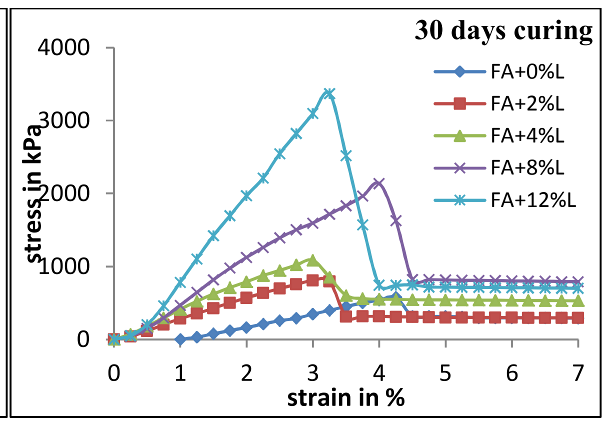


Fig 4.9(iv)

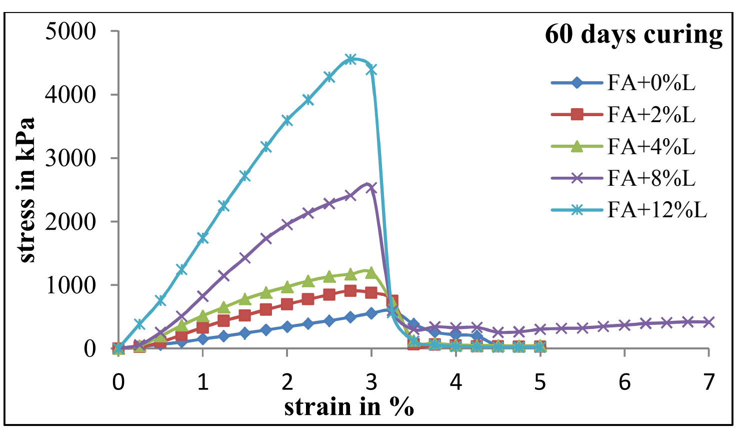


Fig 4.9(v)

Fig 4.9(i)-4.9(v): Stress~strain curve of stabilized flyash prepared at compactive energy of 2483 kJ/m3and cured at 10°C temperature (unsealed samples)

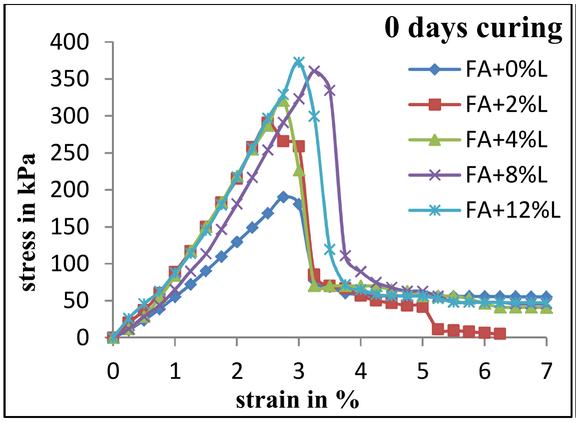


Fig 4.10(i)

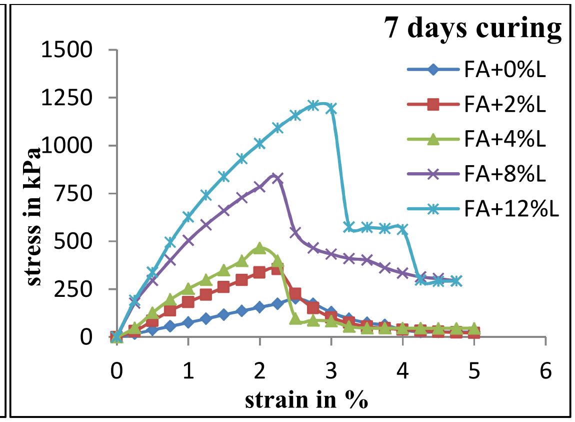


Fig 4.10(ii)

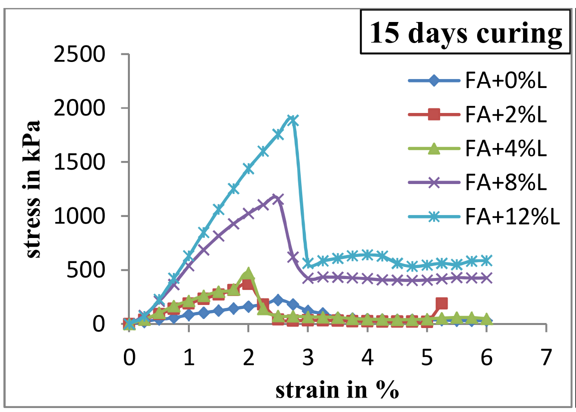
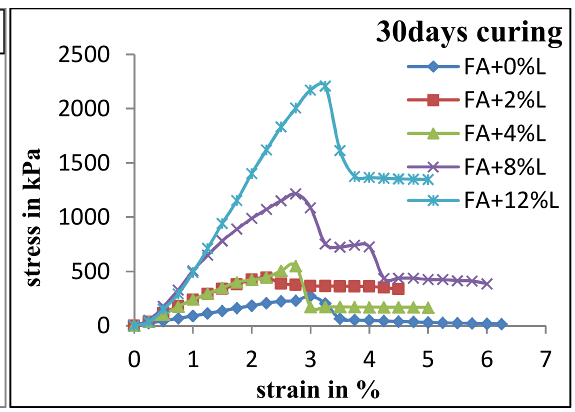


Fig 4.10(iii)



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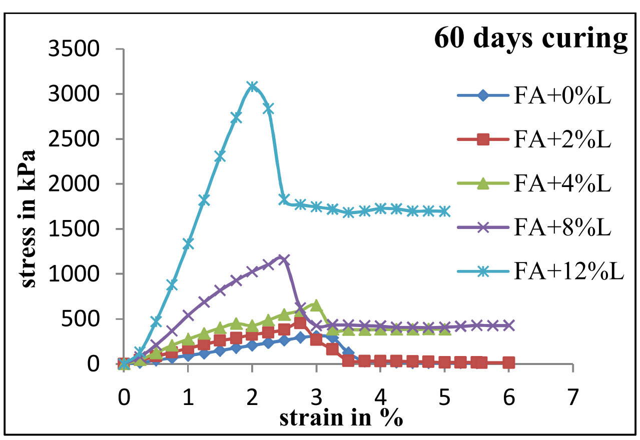


Fig 4.10(iv)

Fig 4.10(i) - 4.10(v): Stress~strain curve of stabilized flyash prepared at compactive energy of 595 kJ/m3and cured at 25°C temperature (sealed samples)

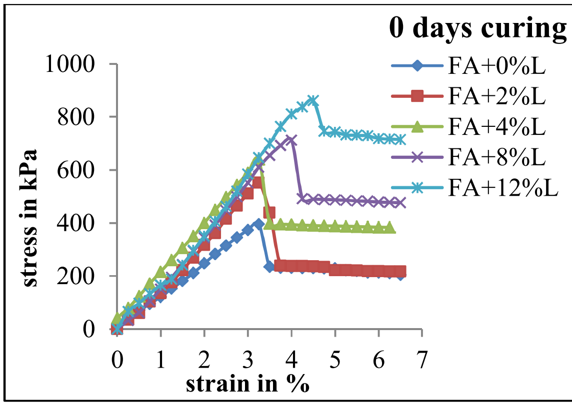


Fig 4.11(i)

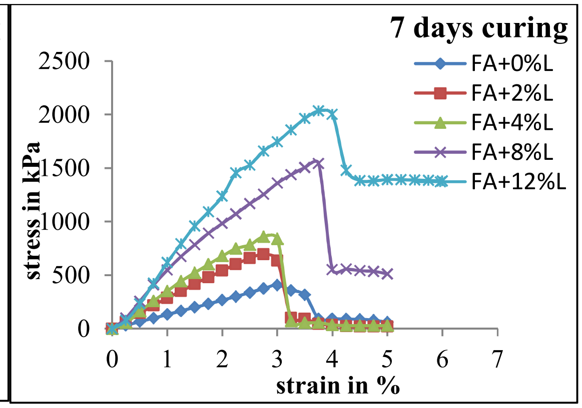
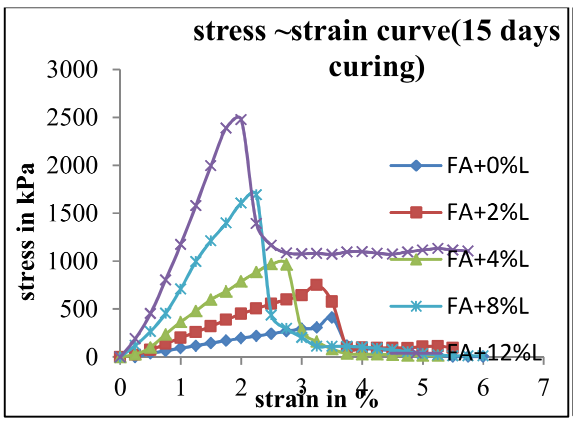


Fig 4.11(ii)



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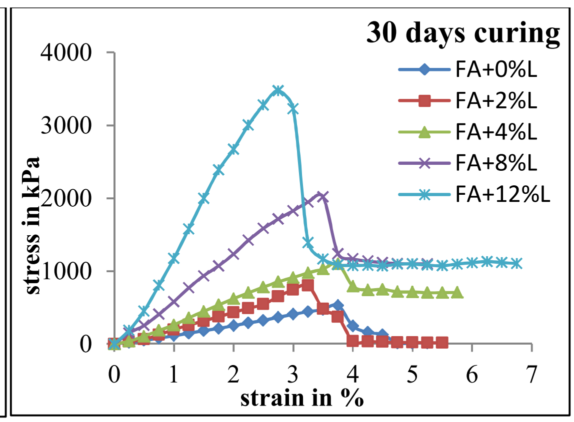

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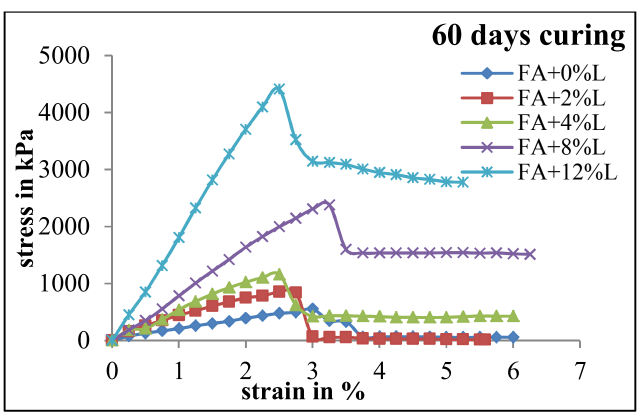
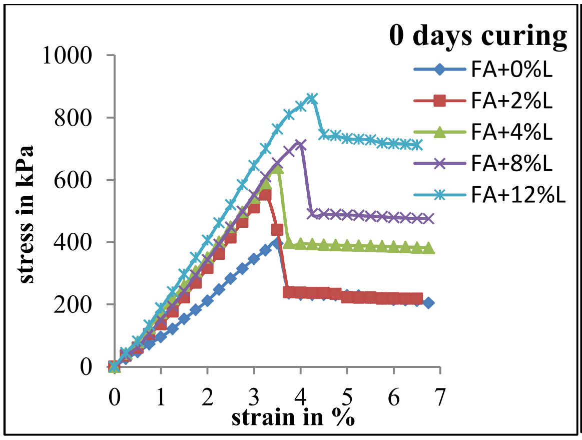


Fig 4.11(v)

Fig 4.11(i)-4.11(v): Stress~strain curve of stabilized flyash prepared at compactive energy of 2483 kJ/m3and cured at 25°C temperature (sealed samples)



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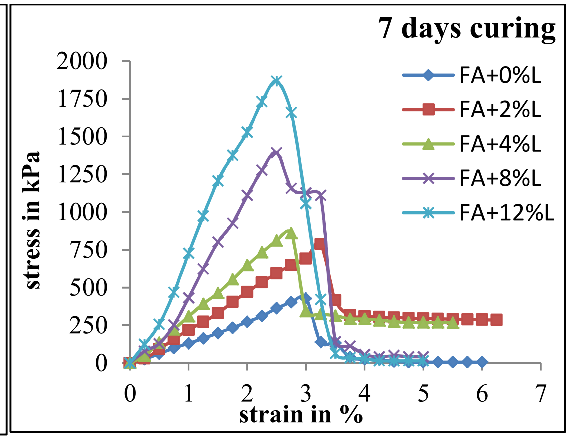
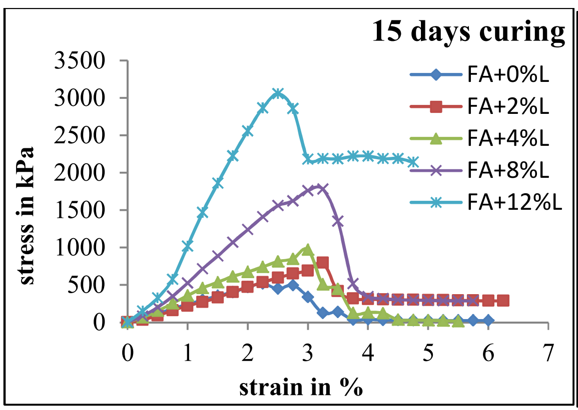


Fig 4.12(iii)



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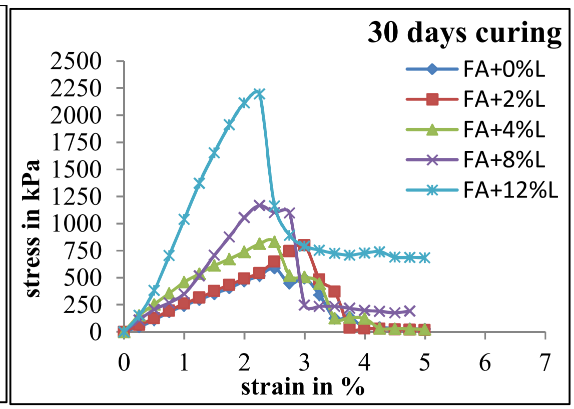

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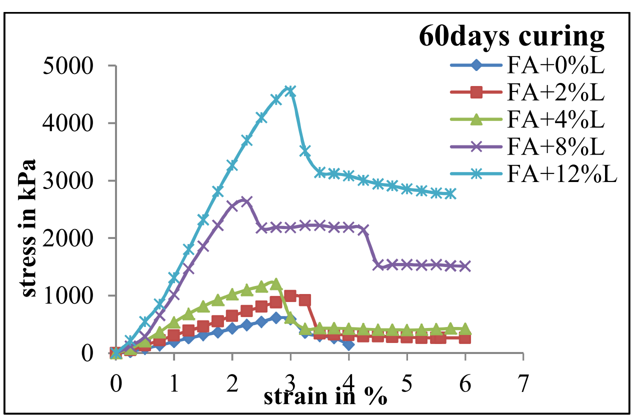


Fig 4.12(v)

Fig 4.12(i)-4.12(v): Stress~strain curve of stabilized fly ash prepared at compactive energy of 2483 kJ/m3 and cured at 25°C temperature (unsealed samples)

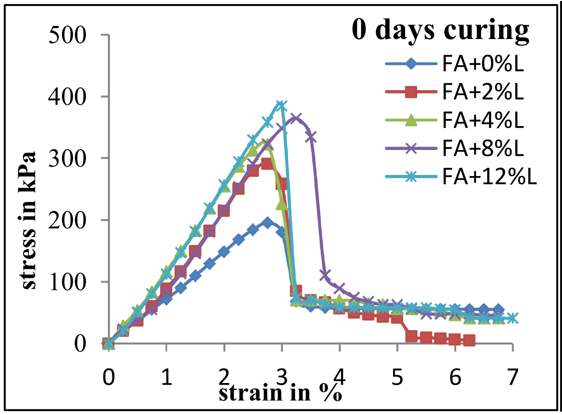


Fig 4.13(i)

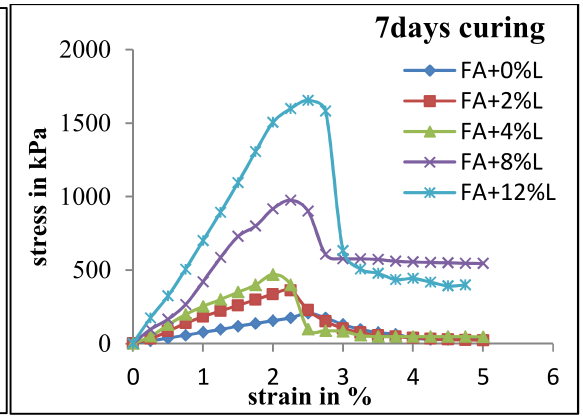


Fig 4.13(ii)

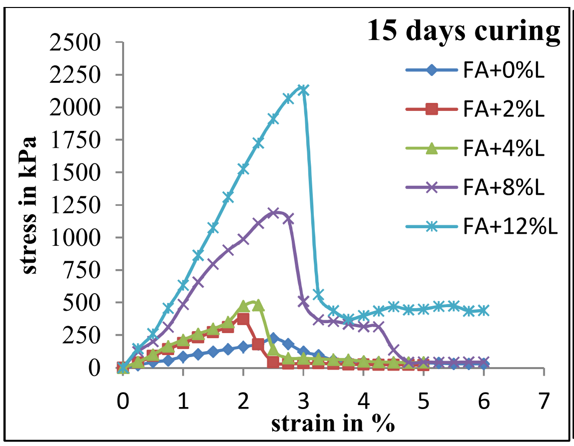


Fig 4.13(iii)

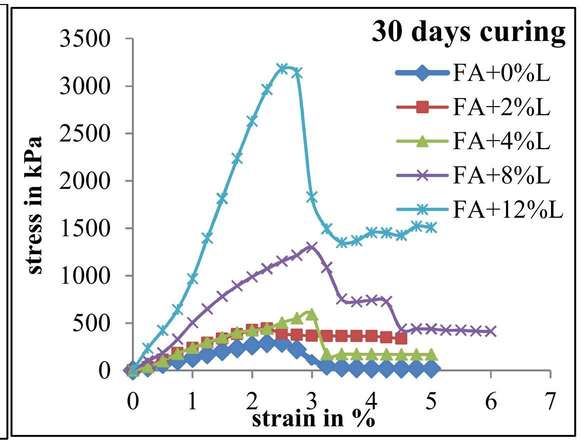


Fig 4.13(iv)

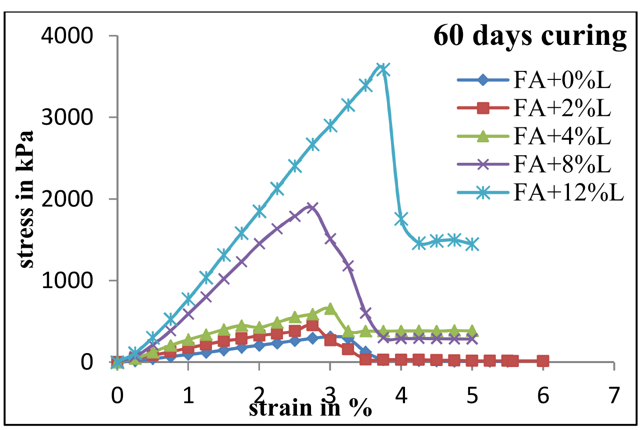


Fig 4.13(v)

Fig 4.13 (i)-4.13(v): Stress~strain curve of stabilized fly ash prepared at compactive energy of 595 kJ/m3 and cured at 45°C temperature (sealed samples)

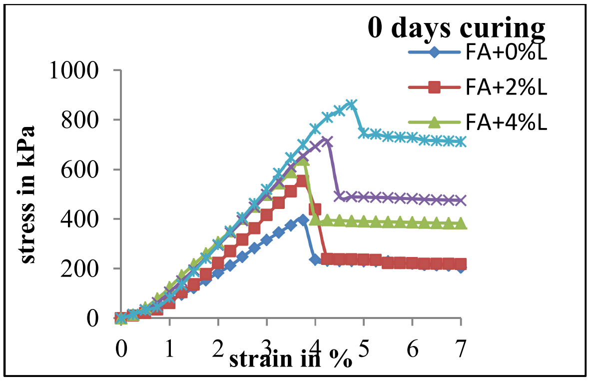


Fig 4.14(i)

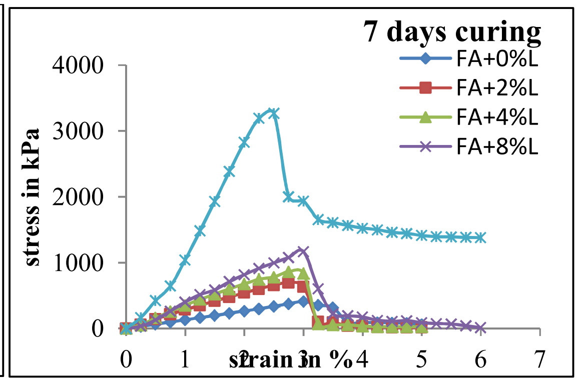
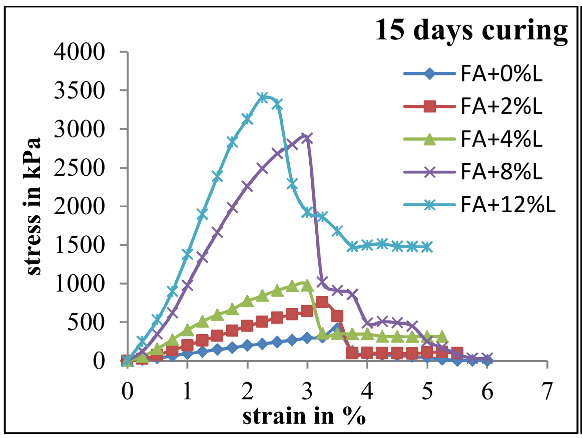


Fig.4.14(ii)



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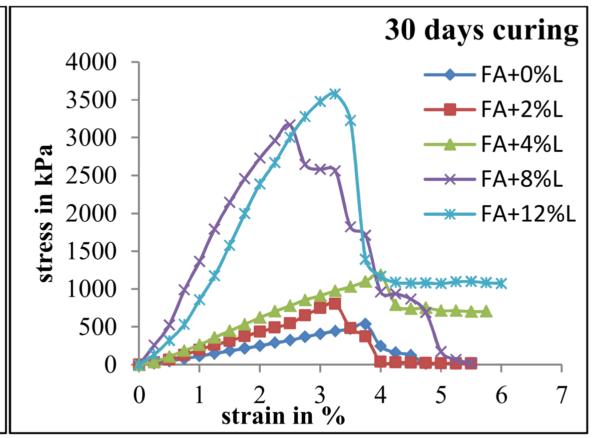


Fig.4.14(iv)

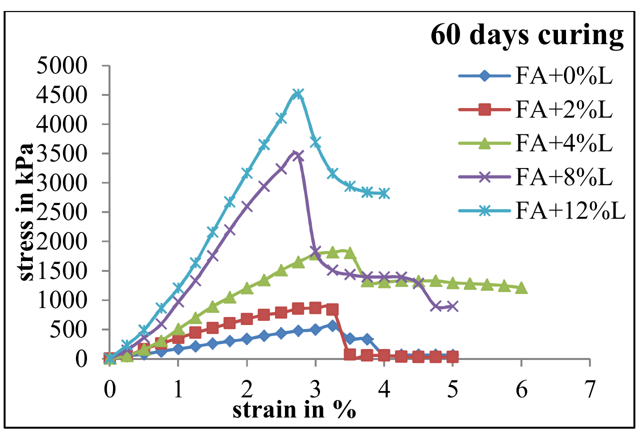


Fig 4.14(v)

Fig 4.14 (i)-fig.4.14(v): Stress~strain curve of stabilized fly ash prepared at compactive energy of 2483 kJ/m3 and cured at 45°C temperature (sealed samples)

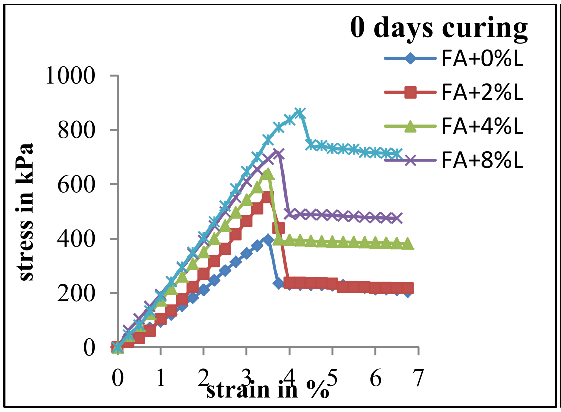


Fig 4.15(i)

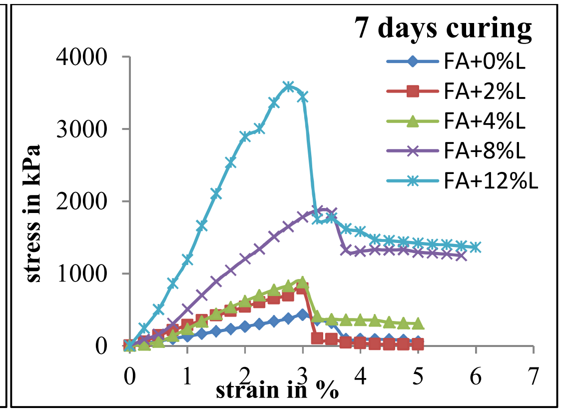


Fig 4.15(ii)

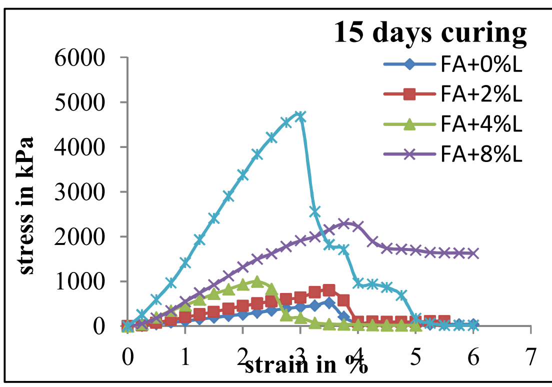
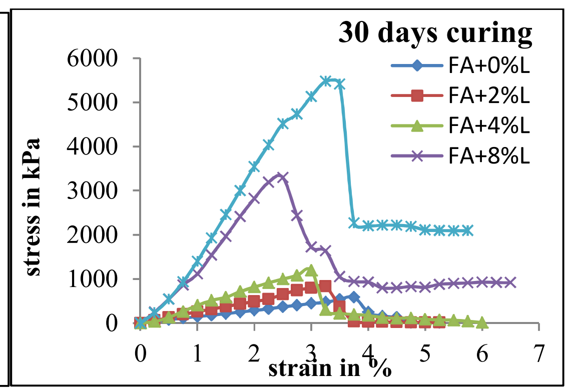


Fig 4.15(iii)



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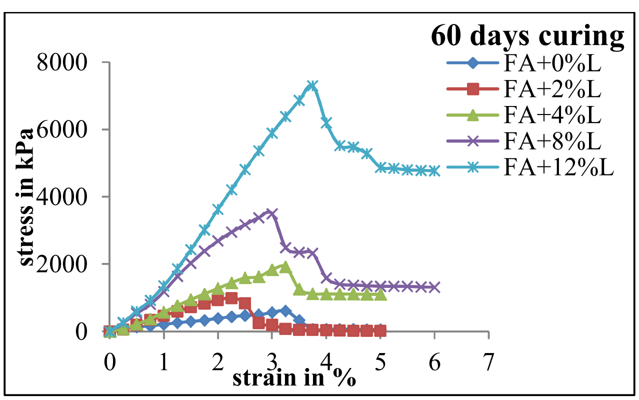


Fig 4.15(v)

Fig 4.15 (i)- Fig4.15.(v): Stress~strain curve of stabilized fly ash prepared at compactive energy of 2483 kJ/m3 and cured at 45°C temperature (unsealed samples)

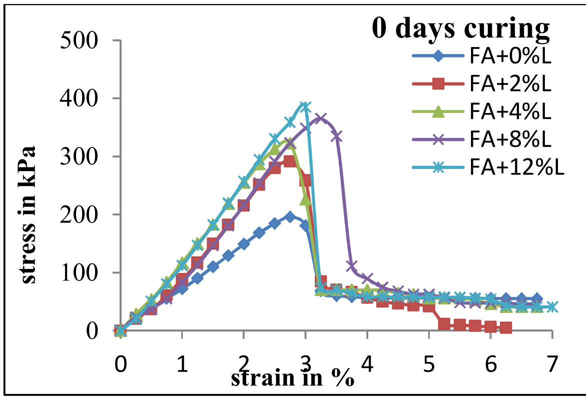


Fig 4.16(i)

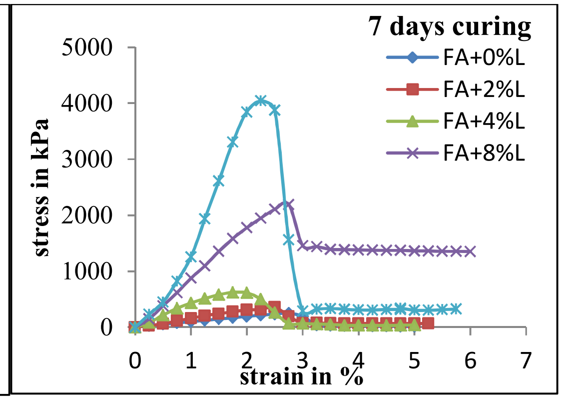


Fig 4.16(ii)

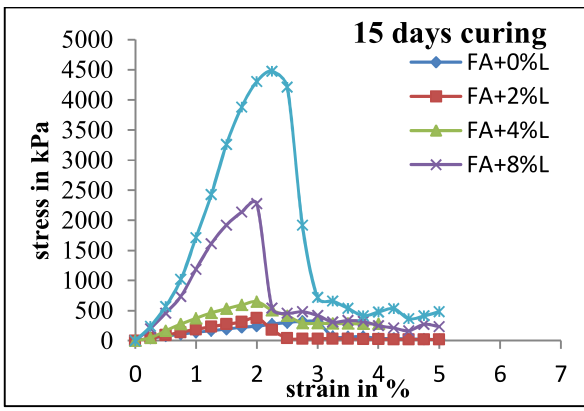


Fig 4.16(iii)

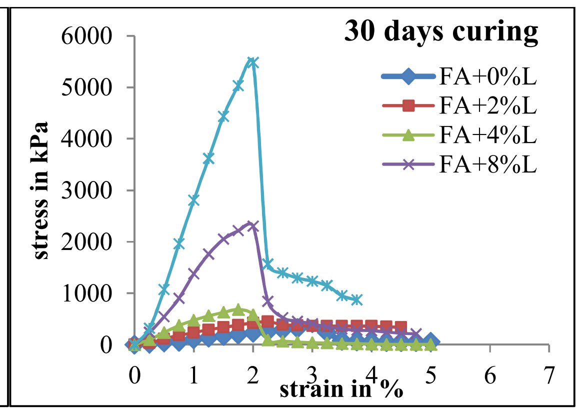


Fig 4.16(iv)

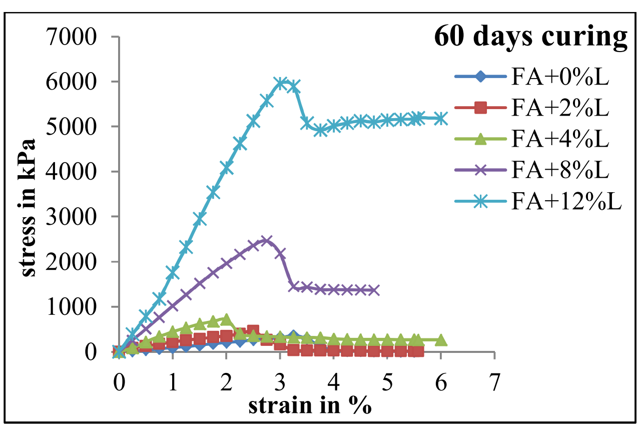


Fig 4.16(v)

Fig 4.16 (i)-Fig4.16(v): Stress~strain curve of stabilized fly ash prepared at compactive energy of 595 kJ/m3 and cured at 90°C temperature (sealed samples)

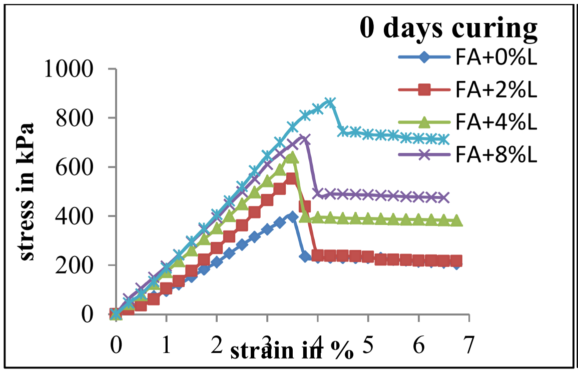
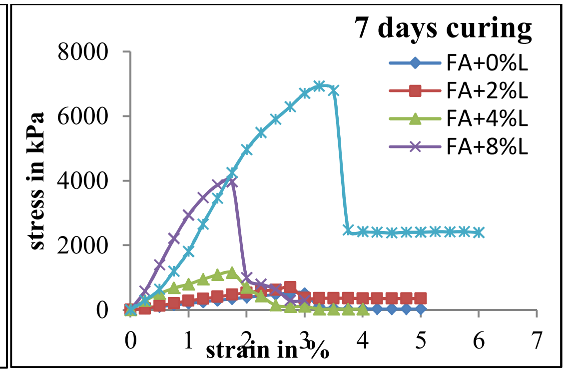


Fig 4.17(i)



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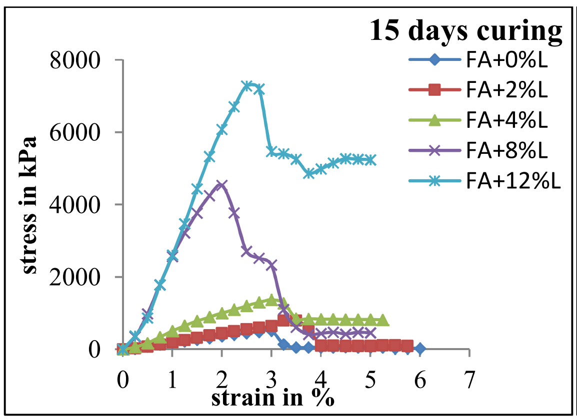

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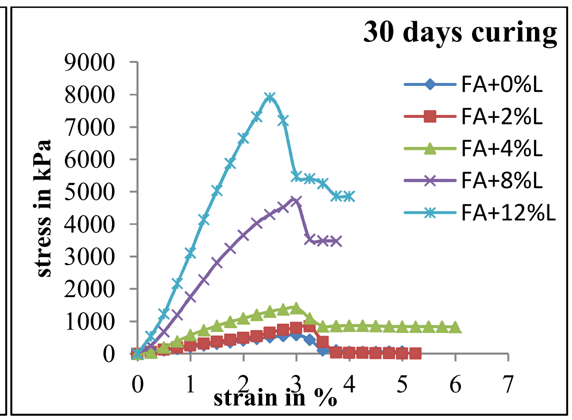

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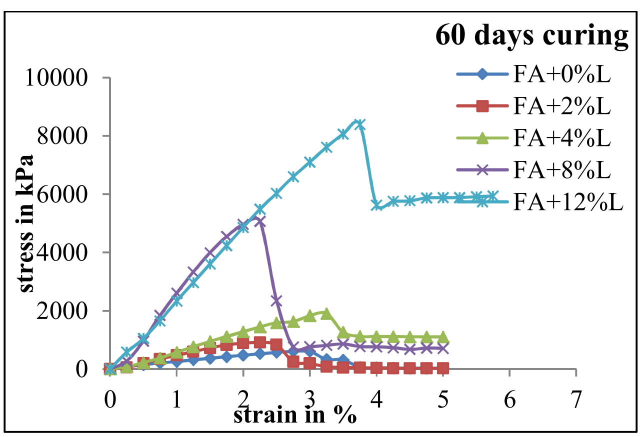


Fig 4.17(v)

Fig 4.17 (i)-Fig.4.17(v): Stress~strain curve of stabilized fly ash prepared at compactive energy of 2483 kJ/m3 and cured at 90°C temperature (sealed samples)

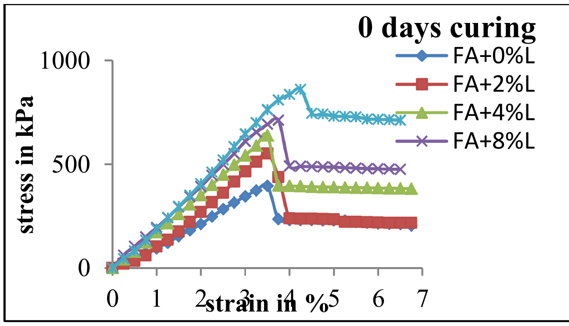


Fig 4.18(i)

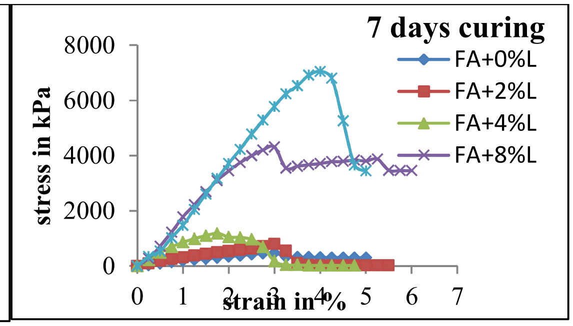
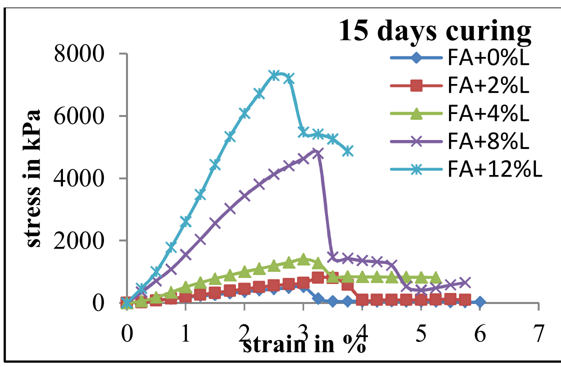


Fig 4.17(ii)



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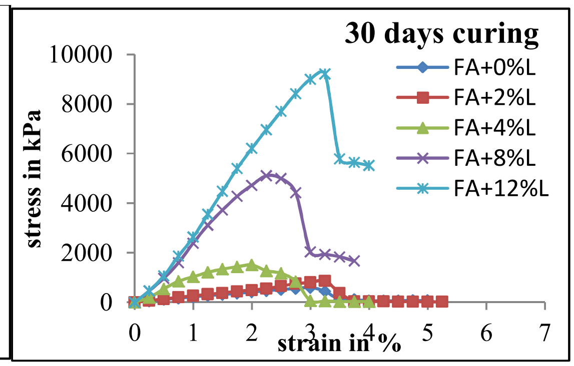

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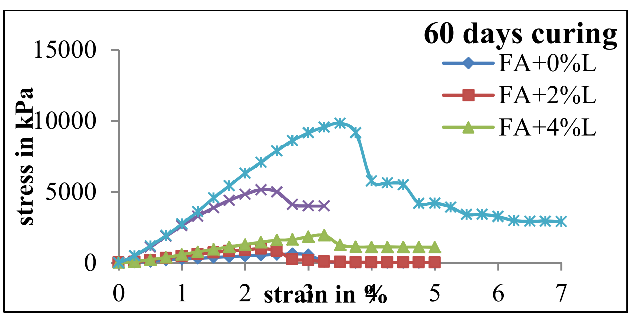

Fig 4.18(v)

Fig 4.18(i)-Fig 4.18(v):Stress~strain curve of stabilized fly ash prepared at compactive energy of 2483 kJ/m3 and cured at temperature 90°C (unsealed samples)

From the above graphs it is visible that the failure stresses of lime stabilized samples, compacted with greater compaction energies, are higher than the samples compacted with lower compaction energy. The failure strains vary from a value of 2 to 3.5 %, indicating brittle failures in the specimen. Increase in curing period of lime treated fly ash specimen shows improvement in the

UCS value. But with smaller amount of lime that is 1%-2% the strength improvement is practically negligible, even if cured for long time.

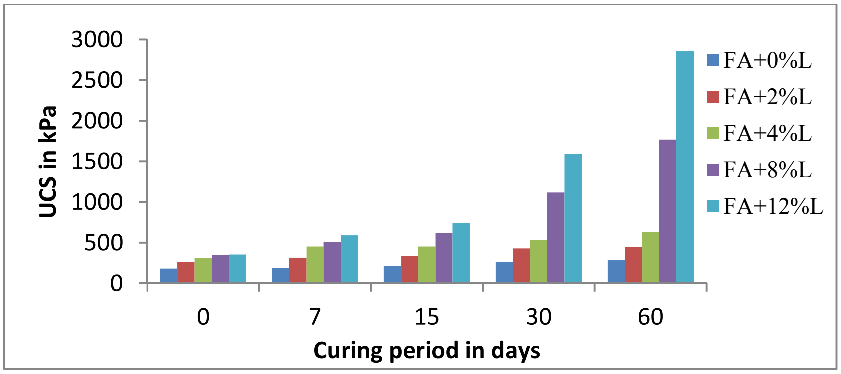

Fig 4.19 (i): Curing period~unconfined compressive strength curve prepared at compactive energy 595kJ/m3 and cured at 10°C temperature (sealed samples)

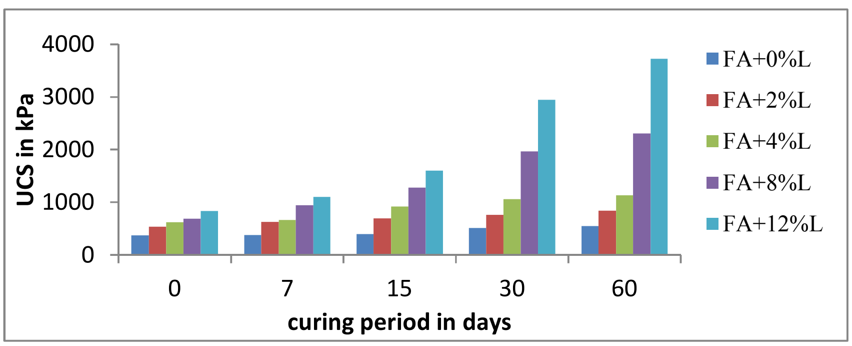

Fig 4.19(ii) Curing period~unconfined compressive strength curve prepared at compactive energy 2483kJ/m3 and cured at 10°C temperature (sealed samples)

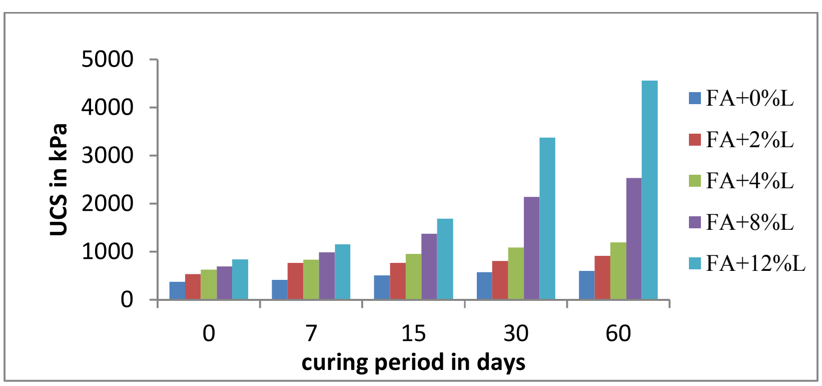

Fig 4.19(iii) Curing period~unconfined compressive strength curve prepared at compactive energy 2483kJ/m3and cured at 10°C temperature (unsealed samples)

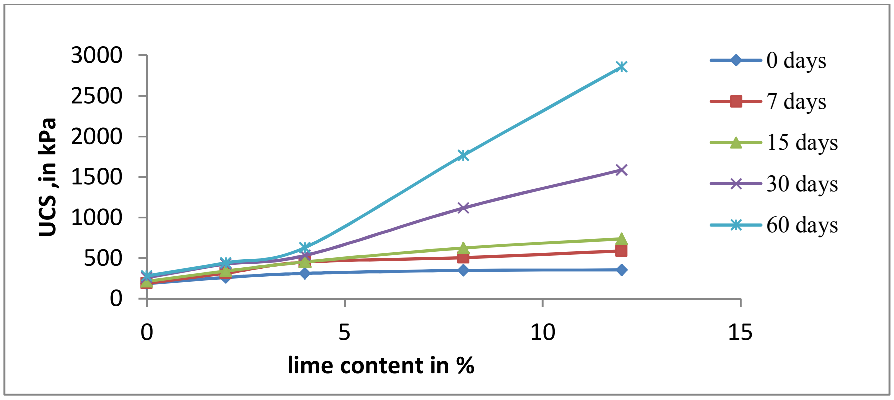

Fig 4.20(i): Lime content vs. unconfined compressive strength curve at compactive energy 593kJ/m3at temperature 10°C (sealed samples)

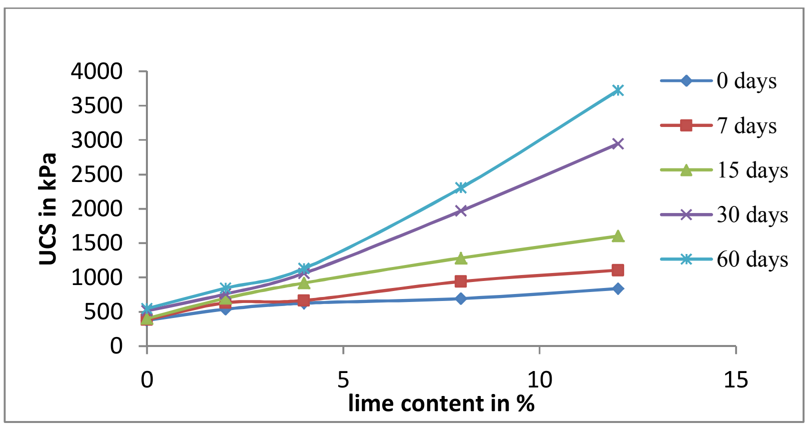

Fig 4.20(ii): Lime content vs. unconfined compressive strength curve at compactive energy 2483kJ/m3at temperature 10°C (sealed samples)

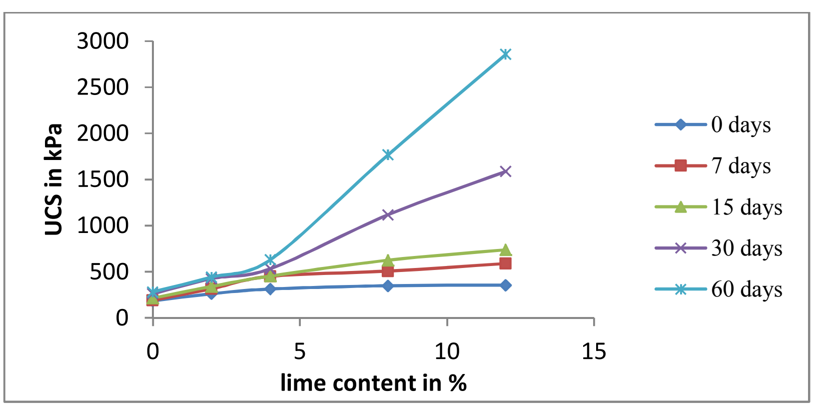

Fig 4.20(iii) Lime content vs. unconfined compressive strength curve at compactive energy 2483kJ/m3at temperature 10°C (unsealed samples)

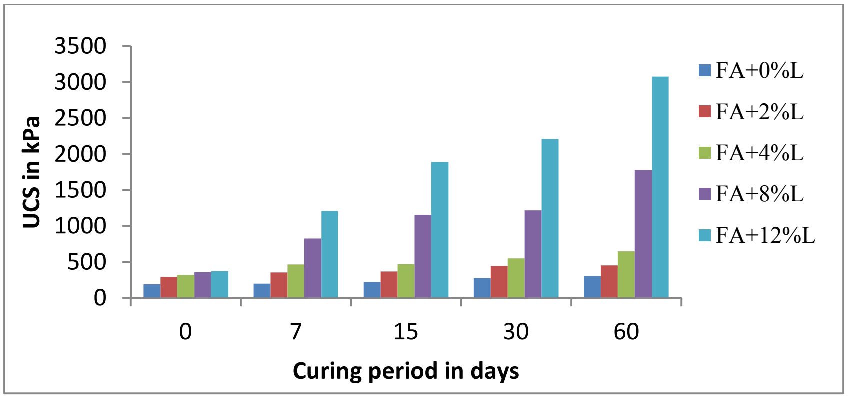

Fig 4.21(i): Curing period~unconfined compressive strength curve prepared at compactive energy 595kJ/m3 and cured at 25°C temperature (sealed samples)

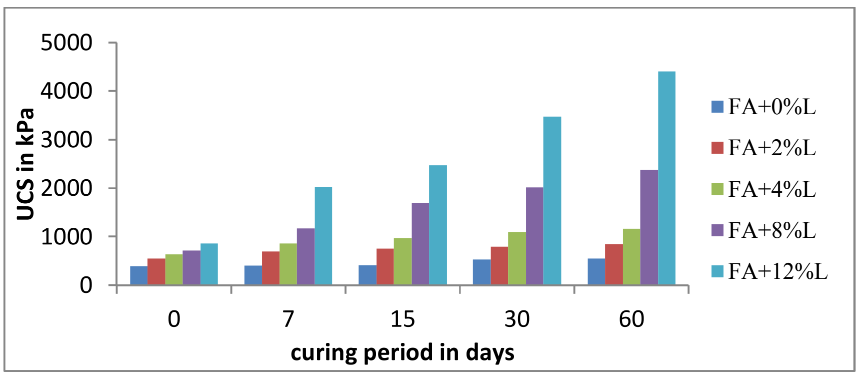

Fig 4.21(ii): Curing period~unconfined compressive strength curve prepared at compactive energy 2483kJ/m3 and cured at 25°C temperature (sealed samples)

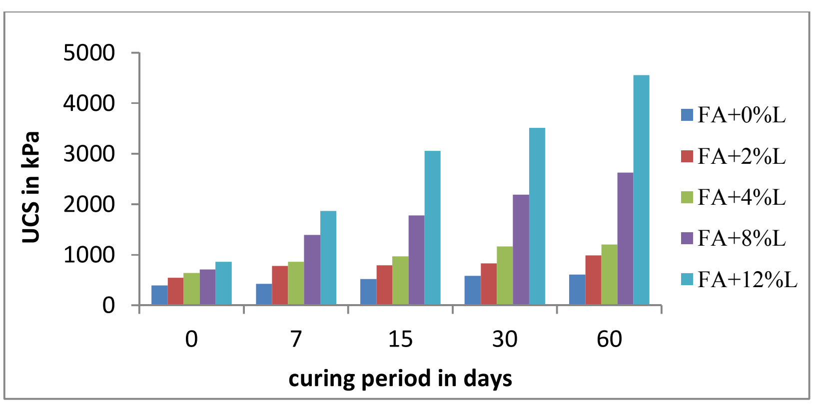

Fig 4.21(iii): Curing period~unconfined compressive strength curve prepared at compactive energy 2483kJ/m3 and cured at 25°C temperature (unsealed samples)

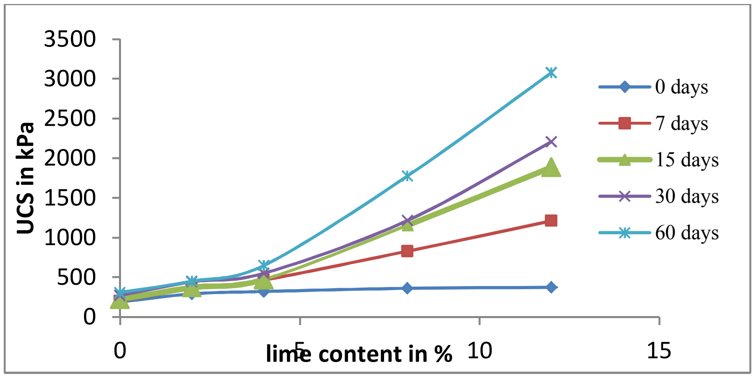

Fig 4.22(i): Lime content vs. unconfined compressive strength curve at compactive energy 595kJ/m3at temperature 25°C (sealed samples)

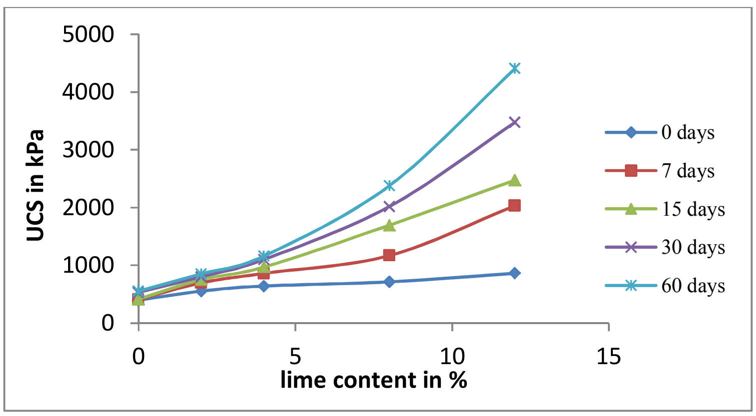

Fig 4.22(ii): Lime content vs. unconfined compressive strength curve at compactive energy 2483kJ/m3at temperature 25°C (sealed samples)

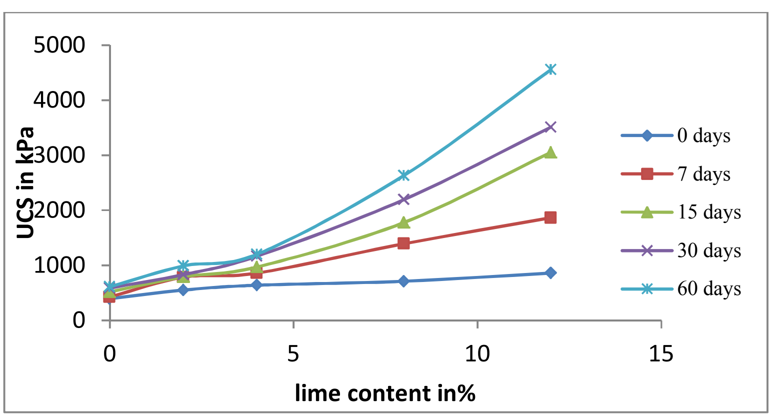

Fig 4.22(iii): Lime content vs. unconfined compressive strength curve at compactive energy 2483kJ/m3at temperature 25°C (unsealed samples)

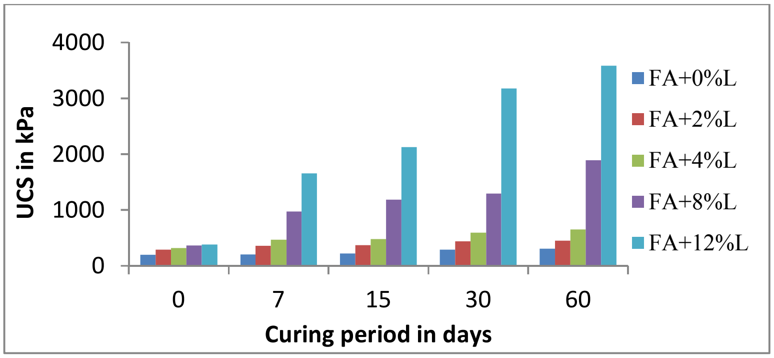

Fig 4.23(i) Curing period~unconfined compressive strength curve prepared at compactive energy 595kJ/m3 and cured at 45°C temperature (sealed samples)

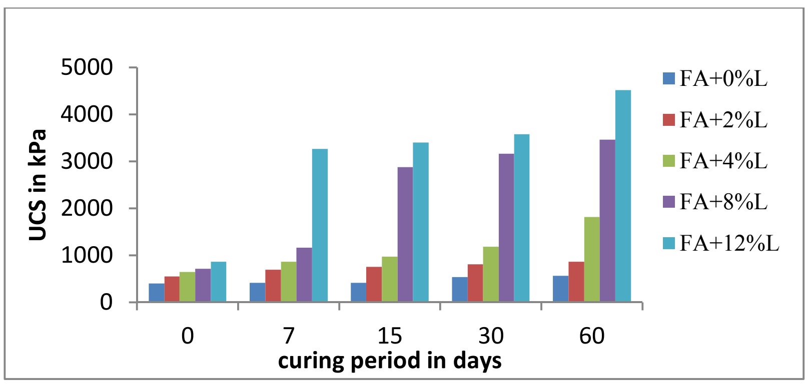

Fig 4.23(ii): Curing period~unconfined compressive strength curve prepared at compactive energy 2483kJ/m3 and cured at 45°C temperature (sealed samples)

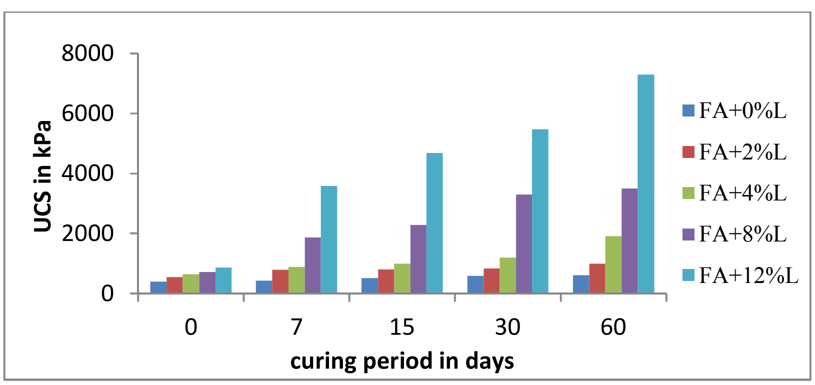

Fig 4.23(iii): Curing period~unconfined compressive strength curve prepared at compactive energy 2483kJ/m3 and cured at 45°C temperature (unsealed samples)

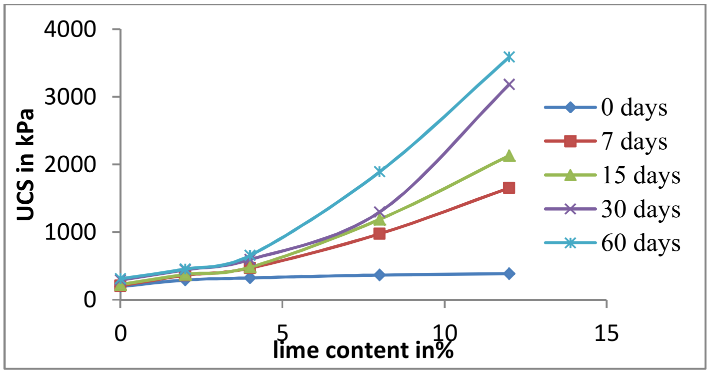

Fig 4.24(i): Lime content vs. unconfined compressive strength curve at compactive energy 595kJ/m3at temperature 45°C (sealed samples)

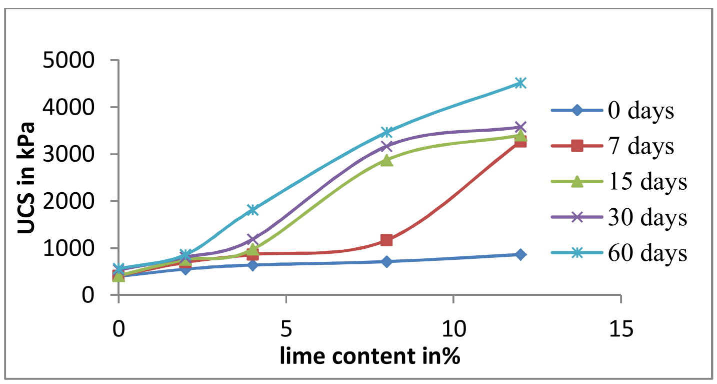

Fig 4.24(ii): Lime content vs. unconfined compressive strength curve at compactive energy 2483kJ/m3at temperature 45°C (sealed samples)

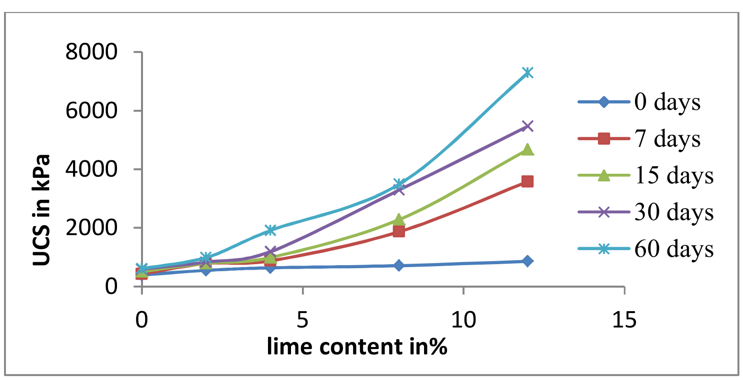

Fig 4.24(iii): Lime content vs. unconfined compressive strength curve at compactive energy 2483kJ/m3at temperature 45°C (unsealed samples)

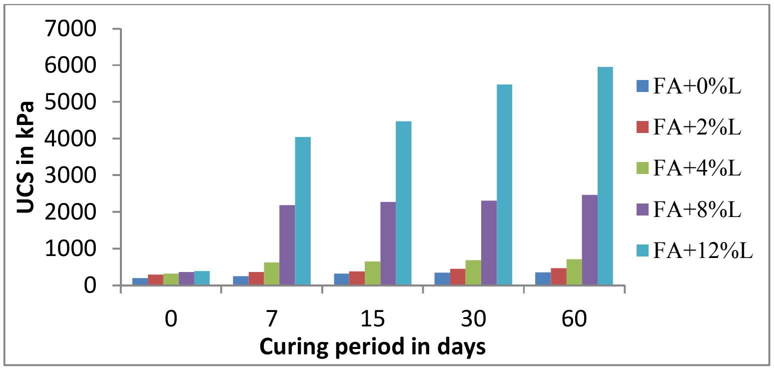

Fig 4.25(i): Curing period~unconfined compressive strength curve prepared at compactive energy 595kJ/m3 and cured at 90°C temperature (sealed samples)

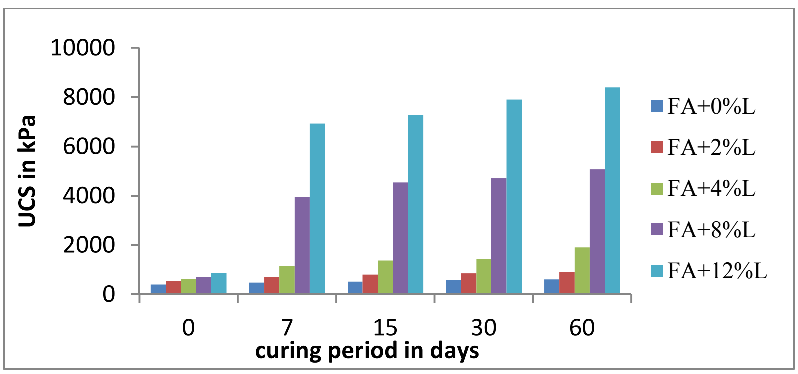

Fig 4.25(ii): Curing period~unconfined compressive strength curve prepared at compactive energy 2483kJ/m3 and cured at 90°C temperature (sealed samples)

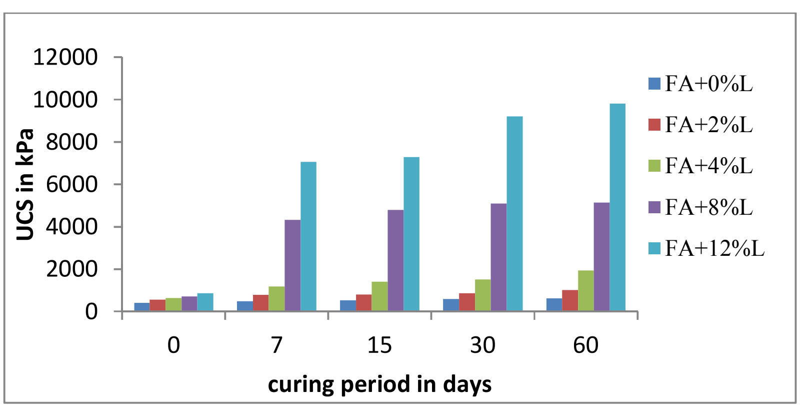

Fig 4.25(iii): Curing period~unconfined compressive strength curve prepared at compactive energy 2483kJ/m3 and cured at 0°C temperature (unsealed samples)

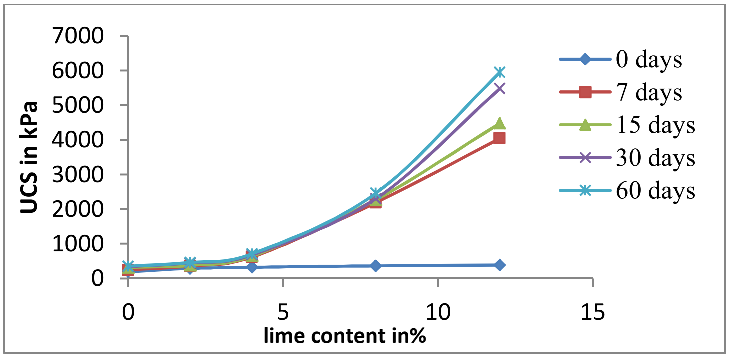

Fig 4.26(i): Lime content vs. unconfined compressive strength curve at compactive energy 595kJ/m3at temperature 90°C (unsealed samples)

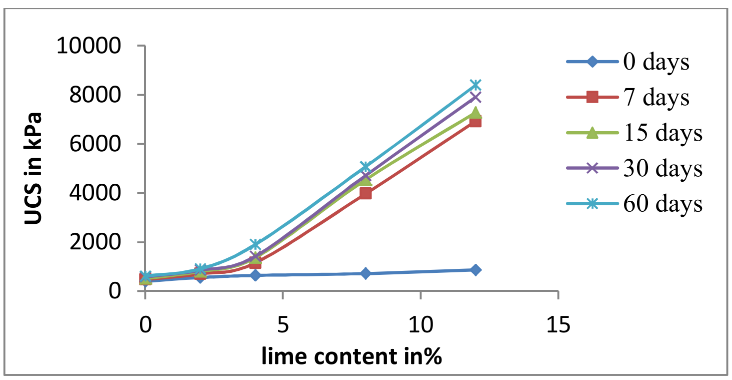

Fig 4.26(ii): Lime content vs. unconfined compressive strength curve at compactive energy 2483kJ/m3at temperature 90°C (sealed samples)

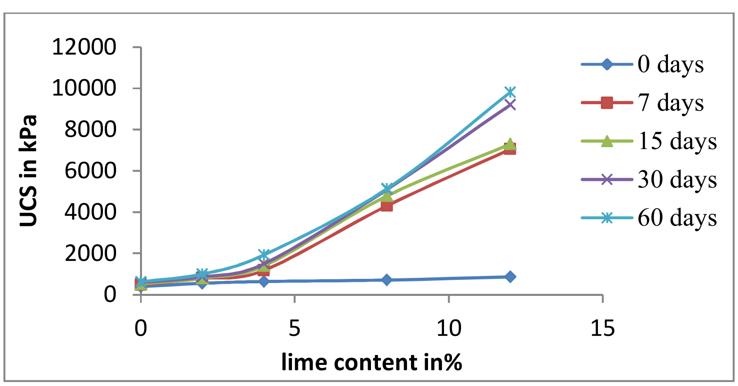

Fig 4.26(iii): Lime content vs. unconfined compressive strength curve at compactive energy 2483kJ/m3at temperature 90°C (unsealed samples)

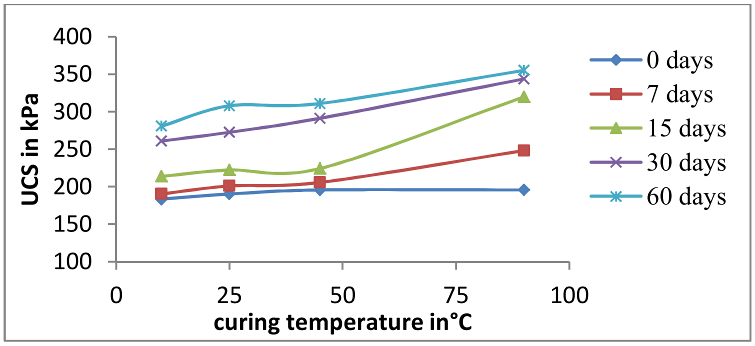

Fig 4.27(i): Temperature vs. unconfined compressive strength curve at compactive energy 595kJ/m3for 0% lime(sealed samples)

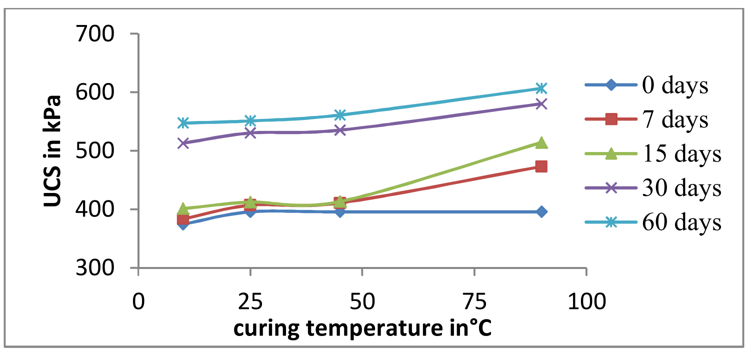

Fig 4.27(ii): Temperature vs. unconfined compressive strength curve at compactive energy 2483kJ/m3 for 0% lime(sealed samples)

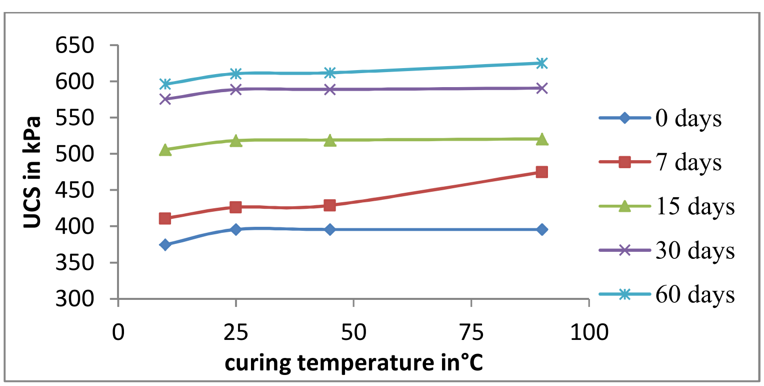

Fig 4.27(iii) Temperature vs. unconfined compressive strength curve at compactive energy 2483kJ/m3for 0% lime(unsealed samples)

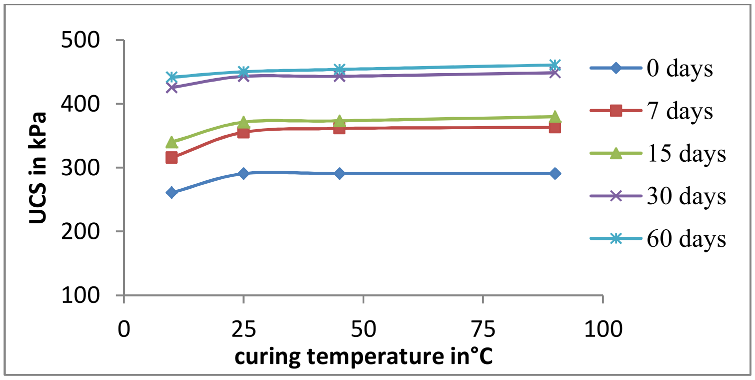

Fig 4.28(i): Temperature vs. unconfined compressive strength curve at compactive energy 595kJ/m3for 2% lime(sealed samples)

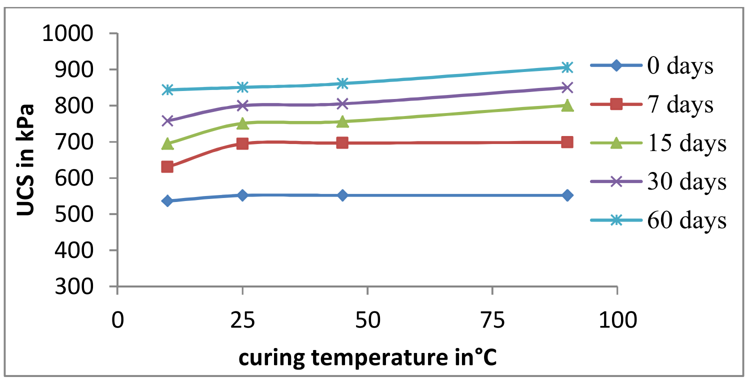

Fig 4.28(ii): Temperature vs. unconfined compressive strength curve at compactive energy 2483kJ/m3for 2% lime(sealed samples)

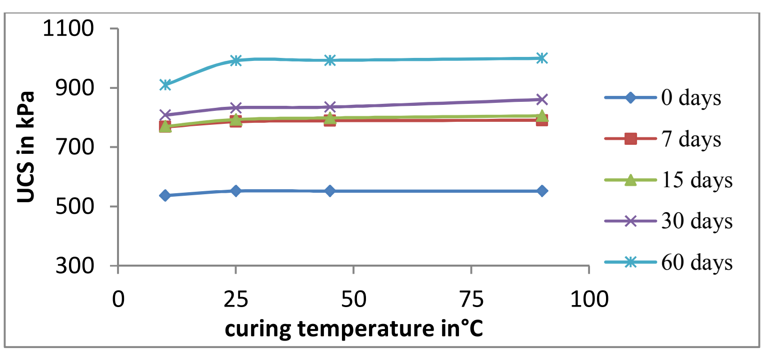

Fig 4.28(iii): Temperature vs. unconfined compressive strength curve at compactive energy 2483kJ/m3for 2% lime(unsealed samples)

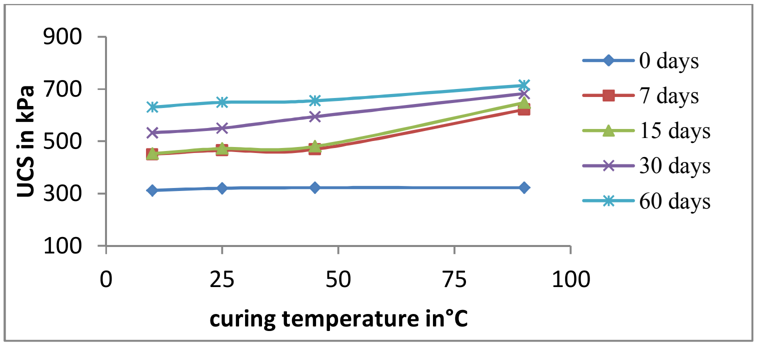

Fig 4.29(i): Temperature vs. unconfined compressive strength curve at compactive energy 595kJ/m3for 4% lime(sealed samples)

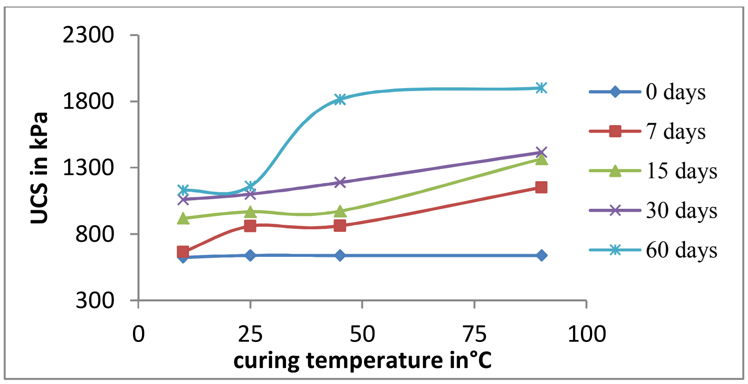

Fig 4.29(ii): Temperature vs. unconfined compressive strength curve at compactive energy 2483kJ/m3for 4% lime(sealed samples)

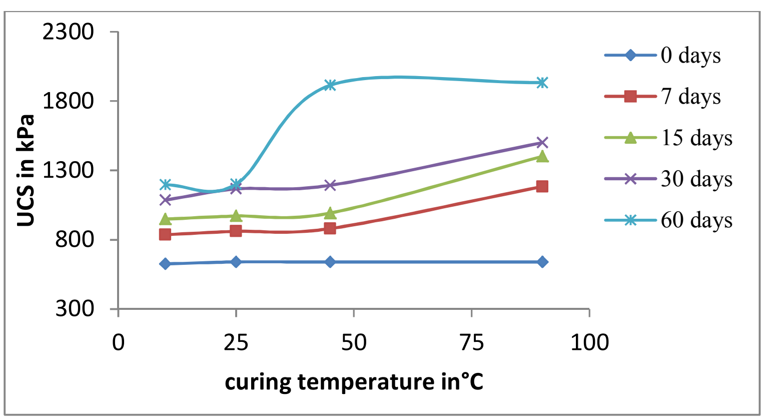

Fig 4.29(iii): Temperature vs. unconfined compressive strength curve at compactive energy 2483kJ/m3for 4% lime(unsealed samples)

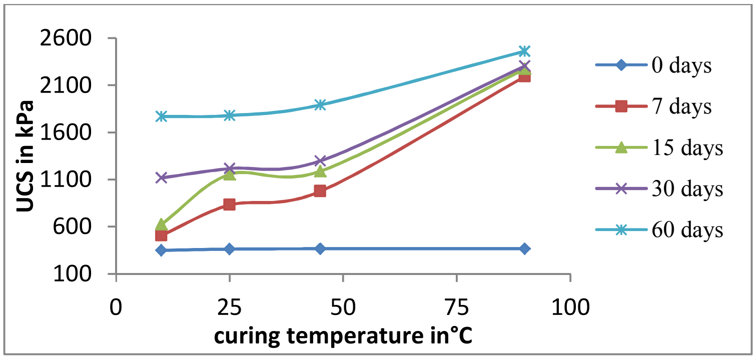

Fig 4.30(i): Temperature vs. unconfined compressive strength curve at compactive energy 595kJ/m3for 8% lime(sealed samples)

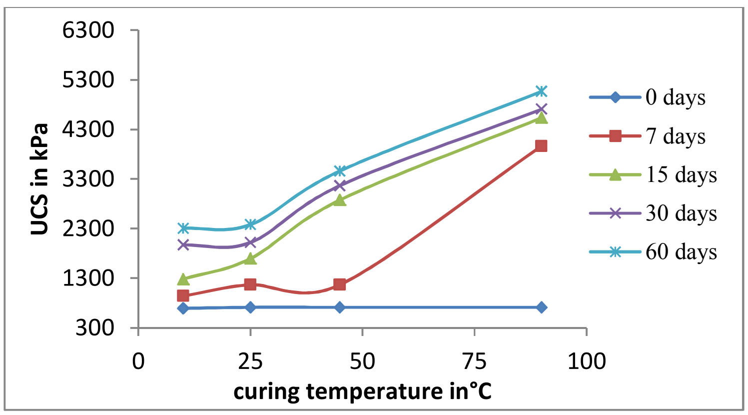

Fig 4.30(ii): Temperature vs. unconfined compressive strength curve at compactive energy 2483kJ/m3for 8% lime(sealed samples)

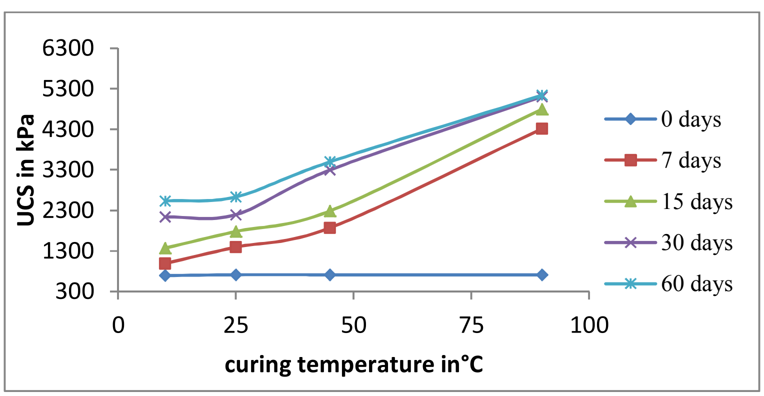

Fig 4.30(iii): Temperature vs. unconfined compressive strength curve at compactive energy 2483kJ/m3for 8% lime(sealed samples)

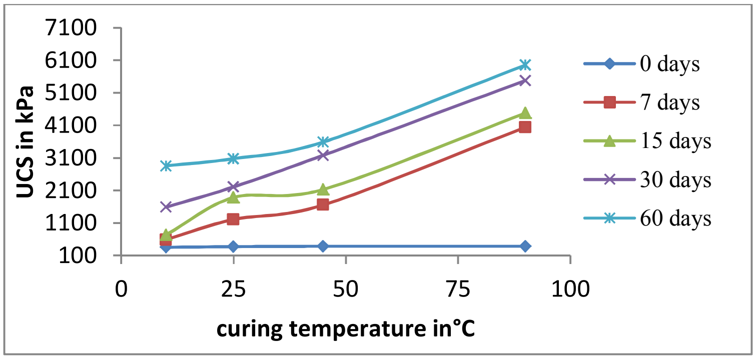

Fig 4.31(i): Temperature vs. unconfined compressive strength curve at compactive energy 595kJ/m3for 12% lime(sealed samples)

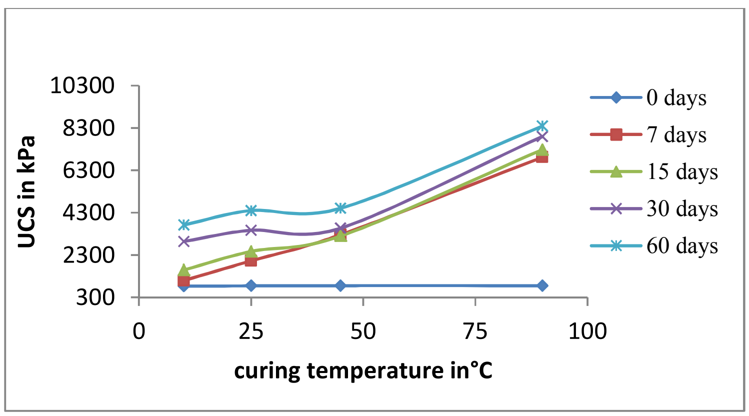

Fig 4.31(ii): Temperature vs. unconfined compressive strength curve at compactive energy 2483kJ/m3for 12% lime(sealed samples)

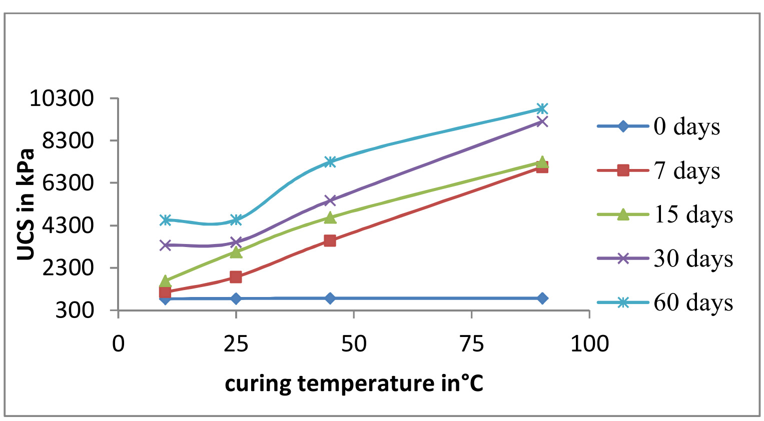

Fig 4.31(iii): Temperature vs. unconfined compressive strength curve at compactive energy 2483kJ/m3for 12% lime(unsealed samples)

4.3.3 Determination of CBR value

CBR-test was conducted to characterize the strength and the bearing capacity of the fly ash. Toth et al. reported the CBR values of coal ashes to vary between 6.8 and 13.5% for soaked condition, and 10.8 and 15.4% for unsoaked condition. The typical CBR value of Badarpur coal ashes tested under soaked and unsoaked conditions reported by Pandian (2004). Basically the unsoaked CBR value is more than soaked CBR value. CBR values under soaked conditions would always give a highly conservative value for design.CBR value increases with increase in compaction energy. The soaked CBR value of Fly ash is relatively low ranging from 1.3%to 5.8% as compaction energy increases from 595 to 2483 kJ/m3. However Lime treated fly ash has comparatively higher CBR value reaching a value of 44.2% at lime content of 10%.when the sample subjected to a curing period of 26 days and a soaking period of 4 days, CBR value considerably increases due to pozzolanic reaction of lime. This is mainly because fly ash, a fine-grained material, when placed at 95% of Proctor maximum dry density and corresponding water content, exhibits capillary forces, in addition to friction resisting the penetration of the plunger and thus high values of CBR are obtained. On the contrary, when the same fly ash samples are soaked for 24 h maintaining the same placement conditions, they exhibited very low values of CBR. This can be attributed to the destruction of capillary forces under soaked conditions. The load Vs penetration curve of lime treated fly ash with 7days and 30 days cured samples are shown below.

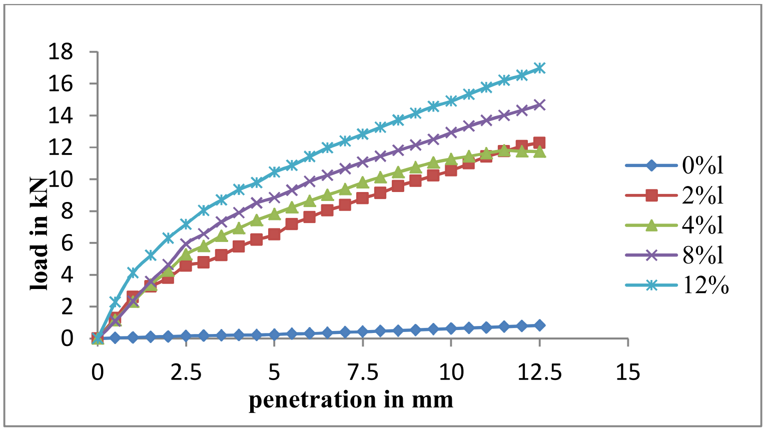

Fig.4.32(i) Load vs penetration curve for 7days soaked CBR at 595kJ/m³

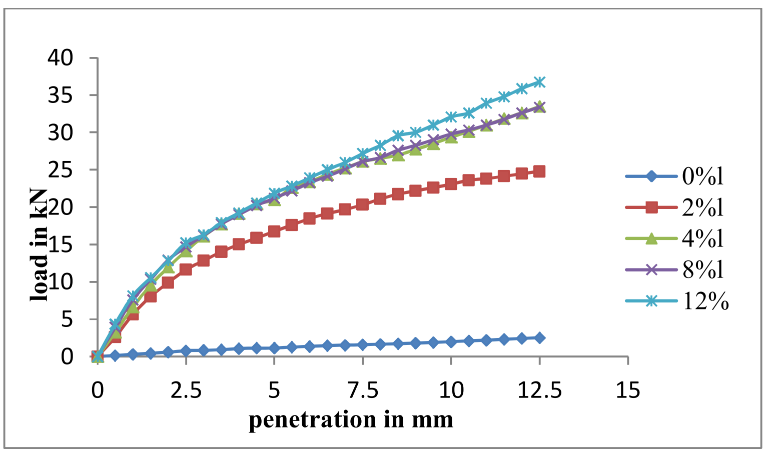

Fig 4.32(ii) Load vs penetration curve for 7days soaked CBR at 2483kJ/m³

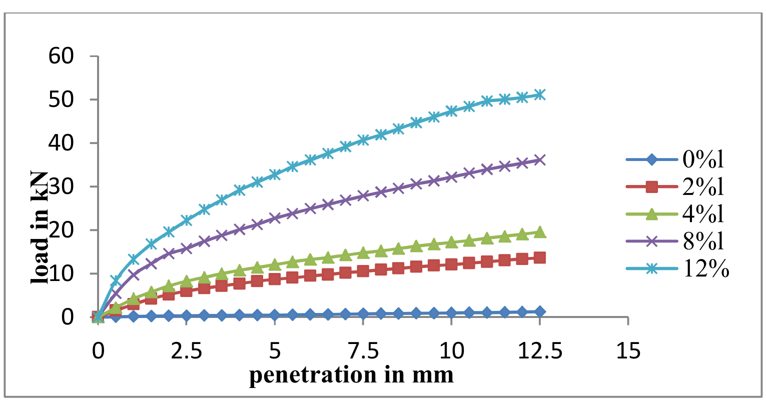

Fig 4.32(iii) Load vs penetration curve for 30days soaked CBR at 595kJ/m³

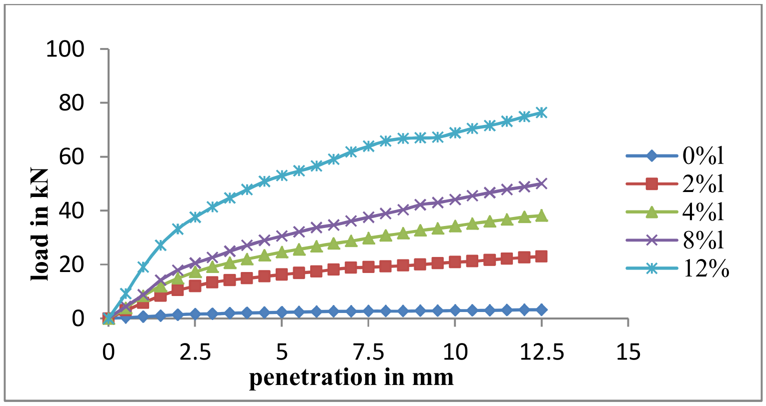

Fig 4.32(iv) Load vs penetration curve for 30days soaked CBR at 2483kJ/m³

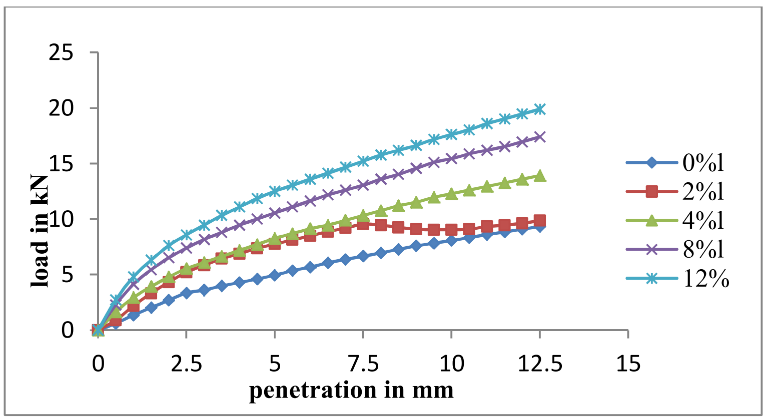

Fig 4.32(v) Load vs penetration curve for 7days unsoaked CBR at 595kJ/m³

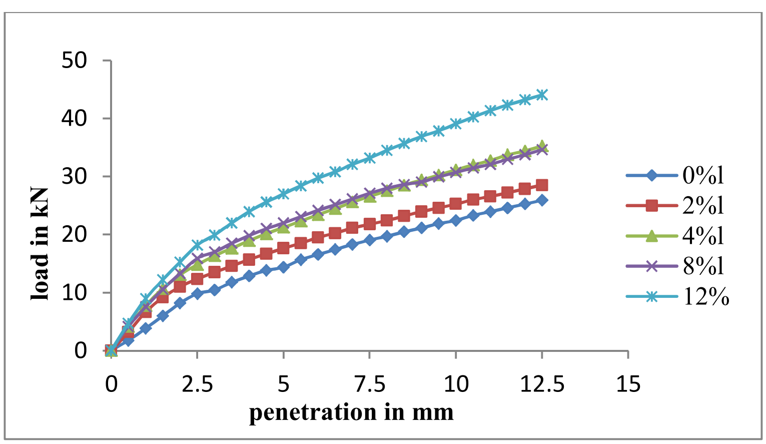

Fig 4.32(vi) Load vs penetration curve for 7days unsoaked CBR at 2483kJ/m³

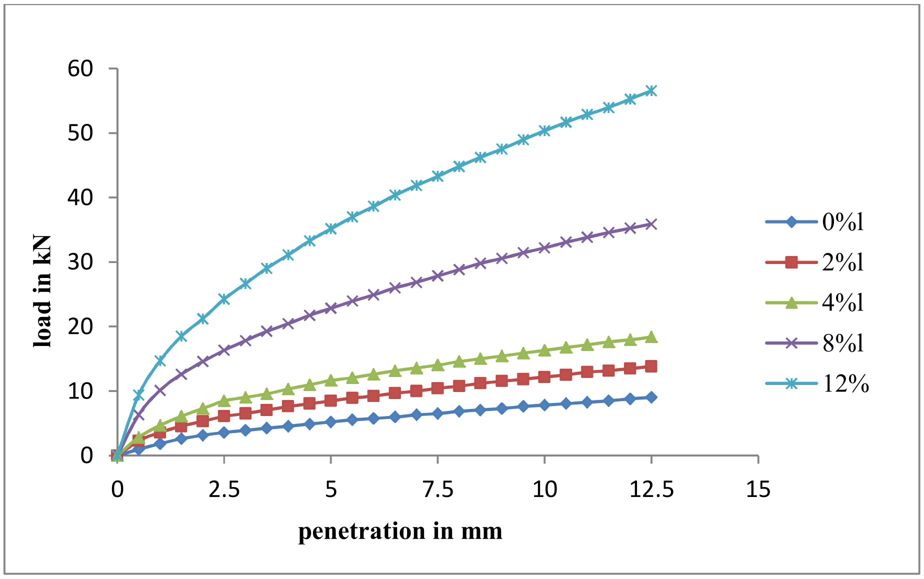

Fig 4.32(vii) Load vs penetration curve for 30days unsoaked CBR at 595kJ/m³

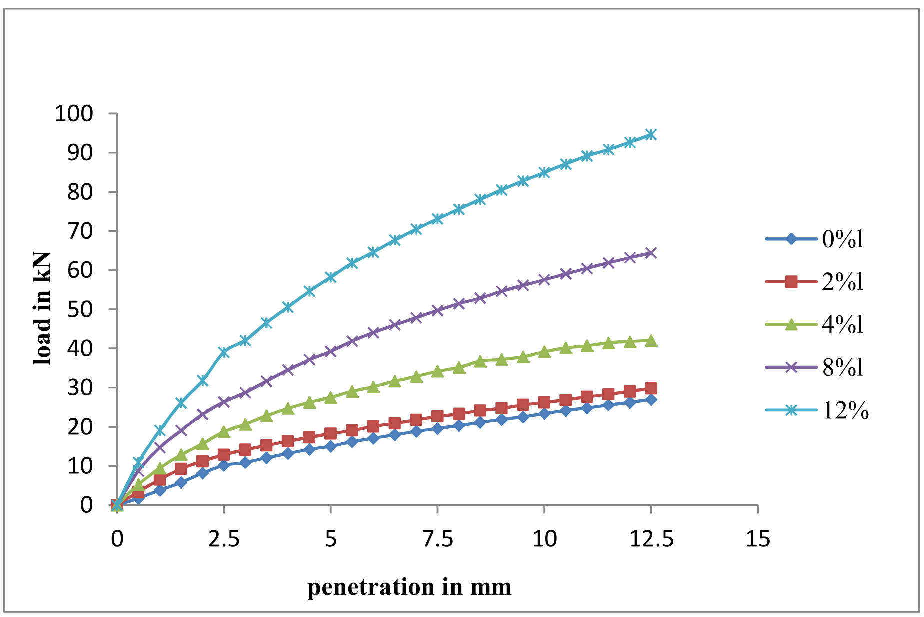

Fig 4.32(viii) Load vs penetration curve for 30days unsoaked CBR at 2483kJ/m³

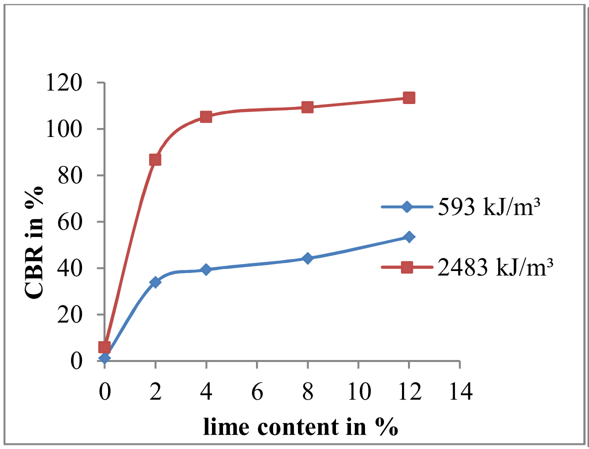

Fig 4.33(i)

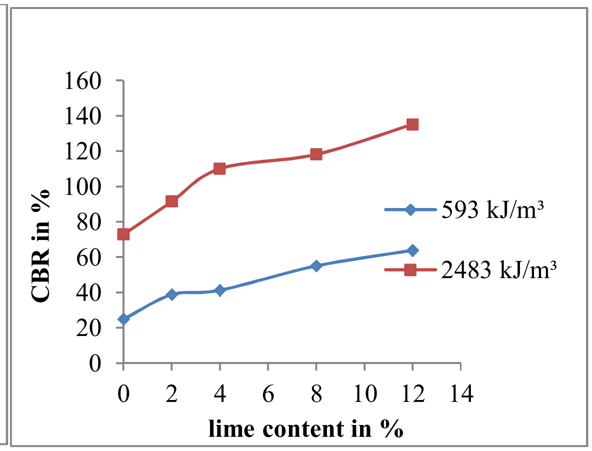

Fig 4.33(ii)

Fig 4.33(i)-4.33(ii) variation of soaked and unsoaked CBR with different lime content for 7days curing period

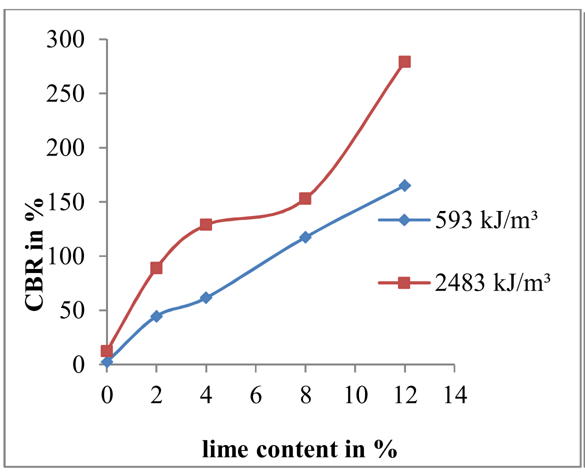

Fig 4.33(i)

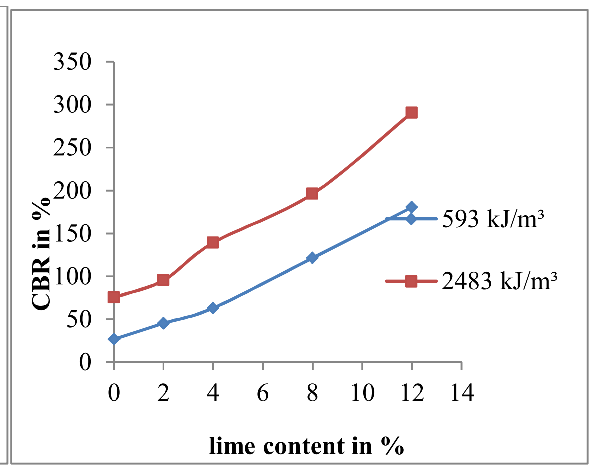

Fig 4.33(ii)

Fig 4.34(i)-4.34(ii) variation of soaked and unsoaked CBR with different lime content for 30days curing period

This graph shows the variation of CBR value due to increase in lime content and curing period with 595 kJ/m3 to 2483kJ/m3 of compactive energy. And it is clearly visible that unsoaked and soaked CBR value of untreated flyash give lesser CBR value when cured for 7days and with curing period increase up to 30 days these values are slightly increased due to presence of some short of cementing material (free lime).And unsoaked and soaked CBR values are found to increase with lime beyond 4% which gives marginal strength. This trend is observed for specimens cured for 7days. However specimens cured for 30 days showed a continuous increase in CBR value. So for better strength higher doses of lime treatment also needed. Test result showed a great variation between unsoaked and soaked CBR values for untreated flyash or flyash treated with low percentage of lime but this difference is reduced when the samples are stabilized with higher percentage of lime.

4.3.4 Permeability characteristics

Variations of Co-efficient of permeability with lime content and curing period are given in table 3.16. Permeabilty decreases with increase in compactive energy. At compaction energy of 2483 kJ/m3 the co-efficient of permeability vary from 3.91×10^{-5}cm/sec for untreated fly ash to 0.474×10^{-5}cm/sec for fly ash treated with 12% lime with 7 days curing. Effect of curing period triggered with the addition of lime result pozzolanic reaction occurs which gives closer packing of particles. Silicon oxide and alumina oxide of fly ash react with lime which generates cementitious gel (CSH) that bind the particles together blocking of the flow paths thus reducing the value of coefficient of permeability. Permeability decreases with increase in compactive energy, lime content or curing period.

CONCLUSIONS AND FURTHER WORK

5.1 Conclusions

Experiments are carried out to investigate strength properties of lime treated flyash. The effects of lime content, curing period and curing temperature on the strength properties are investigated. Based on the experimental investigations the following main conclusions are arrived at:

- The fly ash shows uniform gradation of particles having most of the grains is of fine sand to silt size. The percentage of flyash passing through 75μ sieve was found to be 88%. Coefficient of uniformity (Cu) and coefficient of curvature (Cc) for flyash was found to be 5.67 & 1.25 respectively, indicating that it is a uniformly graded material..
- Dry density of compacted specimens is found to change from 1.12 to 1.236 g/ccwith change in compaction energy from 595 kJ/$m^3$to 2483 kJ/m^3, whereas the OMC is found to decrease from 40.5 to 33 %. This shows that fly ash sample responds very poorly to the compaction energy. An addition of lime flocculates the particles which results in decrease of dry density and increase in moisture content at a given compactive effort at lower doses of lime. However higher lime content tends to increase the MDD value as the specific gravity of lime is higher than that of the flyash particles.
- The failure stresses of lime stabilized samples, compacted with greater compaction energies, are higher than the samples compacted with lower compaction energy. However the failure strains are found to be lower for samples compacted with higher energies with lower lime content. The failure strains vary from a value of 2 to 3.5 %, indicating brittle failures in the specimen. A linear relationship is found to exist between the lime content and unconfined compressive strength.
- The UCS value is found to change from 290.60 to 320.5 kPa with change in lime content from 0 to 2% indicating that the gain in strength is not so remarkable with smaller amount of lime that is 0 -2% the strength improvement is practically insignificant, even if cured for long time.But a higher dose of lime that is beyond 2% enhances the unconfined strength by many folds. This shows that about 2% of lime is used for colloidal type of reaction and lime in excess to this amount is utilized for pozzolanic reaction and increase in strength.

- Increase in curing period of lime treated fly ash specimen shows improvement in the UCS and CBR value. But with smaller amount of lime that is 1%-2% the strength improvement is practically negligible, even if cured for long time. This is similar to the colloidal reaction with lime, which is mainly responsible in modifying the physical properties not the mechanical strength. With increased lime content the pozzolanic reaction peaks up producing adequate amount of cementitious compounds leading to visible increase in strength. As the lime percentage increases this facilitates the pozzolanic reaction that form cementitious gel that binds the particles. The process of pozzolanic reaction is improved with curing period which results higher strength.
- Curing temperature is found to influence the unconfined strength of both sealed and unsealed samples .The UCS values of flyash added with higher percentage of lime show a remarkable increase in strength with increase curing temperature .however flyash added with lower percentage of lime does not show this trend. This indicates that a higher temperature favours a better pozzolanic reaction than a lower temperature .specially when the lime content is high.
- Both unsealed and sealed samples shows almost comparable strength values when the lime content is when the lime content is low and low curing period .Unsealed samples with higher lime content shows an improved strength over the sealed sample at comparable conditions. The increase in strength is remarkably high with higher curing temperature and longer curing periods. This shows that the water added during moulding of samples is insufficient to complete the pozzolanic reaction especially when the lime content is more. Hence it is recommended that ash samples stabilized with higher amount of lime should either be compacted wet of OMC or sufficient be added subsequently for proper curing.
- The stress strain curves of lime treated flyash specimens show an increase in both the stiffness value and failure stress with increase in lime content. However the failure strain is found to decrease with increase in lime content. This indicates wit addition of lime the samples became more stiff and strong where as it behaves more like a brittle material.

- The unsoaked and soaked CBR value of untreated flyash compacted with energy of 595kJ/m3 to 2483kJ/m3 are found to be 24.89% and 1.3% when cured for 7days and with increase in curing period to 30 days these values are 26.71% and 2.5% respectively. This indicates that CBR value of compacted ash is very susceptible to degree of saturation. A slight increase in CBR value of virgin flyash with curing period indicates the presence of some short of cementing material (free lime) in the sample which undergoes pozzolanic reaction with silica and alumina present in the flyash on adding water.
- Both the unsoaked and soaked CBR values are found to increase with lime content up to 4% beyond which the increment is marginal. This trend is observed for specimens cured for 7days. However specimens cured for 30 days showed a continuous increase in CBR value with lime content. This indicates that the reaction of lime with flyash is slow and a higher curing period is needed to complete the pozzolanic reaction.
- Normally 4 days soaked CBR values are used for design of flexible pavements .the CBR test result showed a great variation between unsoaked and soaked CBR values for untreated flyash or flyash treated with low percentage of lime .however this difference is minimal when the samples are stabilized with higher percentage of lime. This indicates that almost all flyash particles are cemented each other by added lime and saturation of samples has no detrimental effect.
- Permeability decreases with increase in either compactive energy or lime content. Permeability is basically a function of grain size and compactive effort. With increase in lime content, pozzolanic reaction occurs which result in blocking of the flow paths thus reducing the value of coefficient of permeability of the lime treated fly ash specimens.sillicon oxide and alumina oxide of fly ash react with lime which generates cementitious gel (CSH) that bind the particles together blocking of the flow paths thus reducing the value of coefficient of permeability. Permeability decreases with increase in compactive energy, lime content or curing period.

5.2 Future Work

For effective utilization of lime treated fly ash, some more aspects have to be investigated

- Effect of mineral and chemical admixtures like silica fume, glass powder etc
- Durability test to study the durability aspect
- Behaviors of stabilized flyash of perform study of under repeated loading
- Compressibility and Consolidation characteristics of compacted fly ash.
- Studies on microstructure and morphology and correlate this to the developed strength.
- Effectiveness of lime in controlling the leachate quality coming out of flyash.
- Liquefaction susceptibility of fly ash.

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